DEVELOPMENT OF RISK BASED SOIL QUALITY STANDARDS FOR TURKEY

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ABSTRACT

DEVELOPMENT OF RISK BASED SOIL QUALITY STANDARDS FOR TURKEY

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Soil quality standards (SQSs) are one of the most important elements of management system for contaminated sites. In order to manage risks associated with soil contamination, risk based SQSs are used worldwide. However, in Turkey, the Soil Pollution Control Regulation in force was focusing mainly on the use of stabilized sludge on soil and was including standards for a limited number of parameters, mainly metals and some organic chemicals. Thus, existing SQSs were far away from providing common criteria for assessment of the soil quality.

In this study, the aim was to develop human health risk based SQSs for Turkey. For derivation of risk based SQSs, the conceptual framework and technical infrastructure were established. SQSs were derived for 151 chemical substances and for three different land use types by incorporating generic site characteristics for Turkey. Since SQSs are highly sensitive to site conditions and chemical-specific data used in calculations, a Microsoft Excel based exposure model was developed as a technical tool. This tool serves for calculation of generic and site-specific SQSs and maintenance of the currency of the standards by allowing periodic update of data used in calculations. Besides, a hydrogeologic database was developed to provide information on the general soil and hydrogeologic characteristics that are used in derivation of SQSs. This database is ultimately, expected to serve for development of conceptual site models, sampling strategies, and derivation of dilution factors during risk assessment studies.

As a result, this study presents a general perspective and approach for derivation of human health risk based SQSs. It is believed that the developed conceptual and technical infrastructure will contribute to contaminated site management and risk assessment studies conducted by the regulatory authorities and the other stakeholders in Turkey.

Keywords: Soil Contamination, Soil Quality Standards, Risk Assessment, Exposure Model, Hydrogeological Database

ÖZ

TÜRKİYE’YE ÖZGÜ RİSK BAZLI TOPRAK KALİTESİ STANDARTLARININ GELİŞTİRİLMESİ

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Toprak kalitesi standartları (TKS), kirlenmiş sahalar yönetim sisteminin en önemli bileşenlerinden biridir. Toprak kirliliği nedeniyle ortaya çıkan risklerin yönetimi için risk bazlı TKS dünya çapında kullanılmaktadır. Ancak, Türkiye’de yürürlükte olan Toprak Kirliliğinin Kontrolü Yönetmeliği, ağırlıklı olarak stabilize arıtma çamurlarının toprağa uygulanması konusuna odaklanmakta ve başta metal kirleticiler ve bazı organik kimyasallar olmak üzere sınırlı sayıda parametre için standartlar içermekteydi. Bu yüzden, mevcut TKS toprak kirliliğinin değerlendirilmesi aşamasında yetersiz kalmaktaydı.

Bu tez çalışmasında, Türkiye’ye özgü, insan sağlığı odaklı, risk bazlı TKS’nin geliştirilmesi hedeflenmiştir. Risk bazlı TKS’nin geliştirilmesi için kavramsal çerçeve ve teknik altyapı oluşturulmuştur. Türkiye’ye özgü saha koşulları kullanılarak, 151 çeşit kimyasal ve üç farklı arazi kullanım tipi için TKS hesaplanmıştır. TKS’nın, saha koşullarındaki ve hesaplamalarda kullanılan kimyasala özgü verilerdeki değişimlere duyarlı olması sebebiyle, Microsoft Excel tabanlı bir maruziyet modeli geliştirilmiştir. Bu model, jenerik ve sahaya özgü TKS’nin hesaplanmasına ve hesaplamalarda kullanılan verilerin, dolayısıyla da standartların, periyodik olarak güncellenmesine olanak sağlayacaktır. Ayrıca, TKS’nin hesaplanmasında kullanılan genel toprak ve hidrojeolojik özellikler ile ilgili bilgileri sağlayabilecek bir hidrojeolojik veritabanı oluşturulmuştur. Bu veritabanının, ileride risk değerlendirme çalışmaları sırasında kavramsal saha modellerinin, örnekleme stratejilerinin ve seyrelme faktörlerinin oluşturulması amacına hizmet etmesi beklenmektedir.

Sonuç olarak, bu çalışma insan sağlığı odaklı risk bazlı TKS’nin geliştirilmesi için genel bir bakış açısı ve yaklaşım sunmaktadır. Geliştirilen kavramsal ve teknik altyapının, Türkiye’deki yasal yetkili birimler ve diğer paydaşlar tarafından yürütülecek kirlenmiş sahalar yönetimi çalışmalarına katkı sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Toprak Kirliliği, Toprak Kalitesi Standartları, Risk Değerlendirme, Maruziyet Modeli, Hidrojeolojik Veritabanı

To My Beloved Husband

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This study was a long journey lasted in six and a half years. It's a story of working days and nights. I spent the first two years by working at a job during the day and studying hard for both classes and my research in the mean time. I still remember the long trips from İstanbul to Ankara, which happened in another one and a half year. Being away from my family, my mind was continuously busy for solving challenging problems about my thesis. Against all these difficulties, achieving my goals was really a pleasure. This story always reminds me how much effort I have put to make my thesis better and it will motivate me for future studies.

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ABBREVIATIONS

ADI	Acceptable Daily Intake
AERMOD	The American Meteorological Society/Environmental Protection Agency Regulatory Model
AF	Skin-Soil Adherence Factor
AMS	American Meteorological Society
API	American Petroleum Institute
AT	Averaging Time
ATSDR	Agency for Toxic Substances & Disease Registry
BCF	Bioconcentration Factor
BRIDGE	Background cRiteria for the IDentification of Groundwater thrEsholds Project
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
BW	Body Weight
CalEPA	California EPA
CARACAS	Concerted Action on Risk Assessment for Contaminated Sites
CCME	Canadian Council of Ministers of the Environment
CDI	Chronic Daily Intake of the Chemical
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CGMW	The Commission for the Geological Map of the World
CHC	Chlorinated Hydrocarbons
CIS	Common Implementation Strategy
CLARINET	Contaminated Land Rehabilitation Network for Environmental Technologies
CLEA	Contaminated Land Exposure Assessment
C_{sat}	Soil Saturation Limit
CSF	Cancer Slope Factor for the Chemical
CSM	Conceptual Site Model
DAF	Dilution-Attenuation Factor
DEFRA	Department for Environment, Food and Rural Affairs and the UK Environment Agency

DEM	Digital Elevation Model
DF	Dilution Factor
DISGB	Descriptive Database Infrastructure Specific to Groundwater Bodies
DMİ	The State Department of Meteorology
DNAPL	Dense Non-Aqueous Phase Liquid
DSİ	General Directorate of State Hydraulic Works
EA	Environment Agency
EC	European Commission
ED	Exposure Duration
EDI	Estimated Daily Intake
EEA	European Environment Agency
EF	Exposure Frequency
EFSA	European Food Safety Authority
EGS	EurGeoSurveys
EPA	Environmental Protection Agency
EPACMTP	Composite Model for Leachate Migration with Transformation Products
EQM	Environmental Quality Management
EU	European Union
EU COM	Commission of the European Communities
EV	Event Frequency
FAO	Food and Agriculture Organization of the United Nations
f_{oc}	Fraction of Organic Carbon
GIS	Geographical Information System
GW	Groundwater
GWD	Groundwater Daughter Directive
HBL	Health Based Limit
HC50	Hazardous Concentration 50
HCHs	Hexachlorocyclo-Hexans
HEAST	Health Effects Assessment Summary Tables
HGDB	Hydrogeologic Database
HQ	Hazard Quotient
IAHS	General Assembly of International Association of Hydrogeological Sciences
ID	Index Dose
IEUBK	Integrated Exposure Uptake Biokinetic Model

$IF_{soil/ad}$	Age-Adjusted Soil Ingestion Factor
ILO	The International Labor Organization
IPCS	The International Programme on Chemical Safety
IR	Soil Ingestion Rate
IRIS	Integrated Risk Information System
ISCST3	Industrial Source Complex Short Term – Version 3
JECFA	The Joint FAO/WHO Expert Committee on Food Additives
JMPR	The Joint FAO/WHO Meeting on Pesticide Residues
L(E)Cs	Lethal Effect Concentrations
LOECs	Lowest Observed Effect Concentrations
MCLGs	Non-Zero Maximum Contaminant Level Goals
MCLs	Maximum Contaminant Levels
MoEF	Ministry of Environment and Forestry
MPR	Maximum Permissible Risk
MPR_{human}	Maximum Permissible Risk for intake
MRL	Minimal Risk Level
MTA	Mining Research and Exploration Institute
NAPL	Non-Aqueous Phase Liquid
NCEA	National Center for Exposure Assessment
NCSRP	National Contaminated Sites Remediation Program
NICOLE	Network for Industrially Contaminated Land in Europe
NOAEL	No Observed Adverse Effect Level
NOECs	No Observed Effect Concentrations
NPCA	The Norwegian Pollution Control Authority
NPL	National Priority List
OEHHA	Office of Environmental Health Hazard Assessment
ORNL	Oak Ridge National Laboratory
PAF	Potentially Affected Fraction
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PEF	Particulate Emission Factor
POPs	Persistent Organic Polluters
PPRTVs	Provisional Peer Reviewed Toxicity Values
RAGS	Risk Assessment Guidance for Superfund
RAIS	Risk Assessment Information System
RASA	Regional Aquifer-System Analysis

RBCA	Risk based Corrective Action
REL	Reference Exposure Level
RfC	Reference Concentration
RfD	Reference Dose
RfD_{ABS}	Dermally Adjusted Reference Dose
RfDo	Oral Reference Dose
RISC	Risk-Integrated Software for Clean-ups
RIVM	National Institute of Public Health and Environmental Protection
RME	Reasonable Maximum Exposure
Q/C	Air Dispersion Factor
SA	Skin Surface Area Exposed – Child
SF_{ABS}	Dermally Adjusted Cancer Slope Factor
SF_{O}	Oral Cancer Slope Factor
SFS	Age-Adjusted Dermal Factor
SGV	Soil Guideline Value
SOM	Soil Organic Matter
SPCR	Soil Pollution Control Regulation
SQG_{E}	Environmental Soil Quality Guideline
SQG_{F}	Final Soil Quality Guideline
SQG_{HH}	Human Health Soil Quality Guideline
SQSs	Soil Quality Standards
SSDs	Species Sensitivity Distributions
SSG	Soil Screening Guidance
SSLs	Soil Screening Levels
SSLG	Soil Screening Level Guidance
TBD	Technical Background Document
TCA	Tolerable Concentration in Air
TDI	Tolerable Daily Intake
TEQ	Toxicity Equivalent
TEF	Toxicity Equivalence Factor
TERA	Toxicology Excellence for Risk Assessment
TRL	Target Risk Level
TRD	Toxicological Reference Dose
TSE	Turkish Standardization Institute
TS-266	TSE Standard for Water Intended for Human Consumption
UK	The United Kingdom

US	The United States
USGS	US Geological Survey
UL	Tolerable Upper Intake Level
UNEP	The United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VBA	Visual Basic Applications
VF	Volatilization Factor
VROM	The Ministry of Housing, Spatial Planning and the Environment
WFD	Water Framework Directive
WHO	World Health Organization

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INTRODUCTION

1.1 SOIL CONTAMINATION

Together with air and water, soil constitutes the environment to sustain the life on earth. These three components are closely related to each other through *hydrologic cycle,* which defines the occurrence, exchange and movement of water on the earth. In this respect, soil has two fundamental environmental functions; soil acts as (i) a *receiving medium* for disposal of wastes and (ii) a *natural recharge zone* for surface water and groundwater (Ünlü et al., 2007). As a consequence, the quantity and the quality of surface water and groundwater are directly affected by soil, and because of its role in hydrologic cycle, soil appears as a key element in terms of environmental pollution problems.

Since soil serves as an underlying material for various human activities, it became a receiving body for various contaminants. In many countries, poor waste management practices, discharge of wastewater, application of herbicides and pesticides onto soil for agricultural purposes, spills, leaks and/or discharge of chemicals during handling, storage and transportation result in complex environmental problems threatening human health and ecology. However, chemical releases into soil are not limited with these activities, air emissions resulting from heating processes (e.g., deposition of PAHs), lead smelters (e.g., metal deposition), incineration processes (e.g., deposition of PCDD and PCDF), and traffic also cause significant soil pollution problems (Swartjes, 2011).

Necessary attention had not been paid to soil until late 1970s, since the quality of soil, unlike water and air quality, cannot be observed directly by individuals other than farmers (Swartjes, 2011). Two infamous examples of soil contamination events experienced in the US in 1978 (known as Love Canal disaster) and in the Netherlands in 1979 (known as Lekkerkerk incident) (Swartjes, 2011), which were both arisen due to residential settlement on a former chemical dump site, might be the reason for early creation of awareness in these two countries to soil contamination and for launching researches for development of strategies to combat soil pollution.

Because of the widespread occurrence of soil contamination events and its effects on human health and environment, soil quality has been an issue taken more seriously during the recent decades. Soil and groundwater contamination problems are on the agenda of European and North American Countries for the last 25-30 years (US EPA, 2004a). During this period of time, significant improvements have been recorded related to identification, registration, assessment and clean-up of contaminated sites in terms of frameworks and technological developments. According to European Environmental Agency (EEA) estimates, "potentially soil polluting activities have occurred at about 3 million sites in European Union (EU) countries" and "more than 8% of the sites (nearly 250.000 sites) are contaminated and need to be remediated" (URL 1). EAA declares that "a total budget of 2,250 billion EUR has been allocated for remediation of the contaminated sites in Europe during 2005-2013". However, the annual management cost differs significantly from country to country due to the lack of a common definition among European Countries, use of different approaches for evaluation of the contaminated sites, country-specific properties and the level of industrialization (URL 1).

Since the number of contaminated sites increased significantly, mostly due to industrial activities; many countries, environmental agencies and organizations configuring their framework by integrating efficient management systems for contaminated sites. In the following paragraphs, the examples for the projects that have been carried out across Europe aiming development of appropriate approaches and technologies to confront soil contamination are described.

In order to support scientific cooperation between European countries, a Programme titled CARACAS (the Concerted Action on Risk Assessment for Contaminated Sites) was started in 1996 (Ferguson et al., 1998). The Programme was initiated by the German Federal Ministry for the Environment and coordinated by the Federal Environmental Agency (Ferguson et al., 1998).

The Programme brought the academicians and government experts from 16 European countries together. The working group had focused on the arrangement and enhancement of research studies carried out for assessment of risks arising from contaminated sites (Ferguson et al., 1998).

Another programme co-ordinated by the Austrian Federal Environment Agency performed between 1998-2001 and funded by European Commission was the network CLARINET (Contaminated Land Rehabilitation Network for Environmental Technologies). In this network, "academicians, national policy makers, government experts, consultants, industrial land owners and technology developers from 16 European countries" came together and shared their knowledge and experience (Vegter et al., 2002). The objective of the network was to determine the basis for effective management of contaminated sites that ensures protection of surface and groundwater systems. The main finding of the CLARINET was "*the importance of management of contaminated sites with risk based approaches"* (Vik et al., 2002).

Likewise, NICOLE (Network for Industrially Contaminated Land in Europe) brought experts from 17 EU countries together to share their experiences and findings related with industrially contaminated sites (NICOLE, 2002). The network, which initiated in 1996 under the 4th Framework Programme of the European Community, continues to work as a "self supporting network financed by the fees of its members" (NICOLE, 2002). Today, NICOLE supplies technical aid for site-specific risk assessment studies which constitutes the basis for management of contaminated sites (NICOLE, 2002).

In the line of these projects, a common ground has been developed in EU level for adoption of risk based management systems for contaminated sites. The findings, experiences and the knowledge gained through the abovementioned projects were then transferred to the documents published by the EU Commission. With the document titled "Towards a Thematic Strategy for Soil Protection" (EU COM, 2002), the importance of soil protection against pollution has been emphasized at EU level for the first time. This document aimed to build the political liability to achieve soil protection in a systematic manner. In order to achieve this objective, it has been declared that the situation in Europe should be considered from "local, national and general" perspectives. With the insight of these studies, for sustainable management of soil "Thematic Strategy for Soil Protection", which designates the local and diffuse contamination as one of the important threats on soil, was published under the 6th Environment Action Programme of the EU (EU COM, 2006a). Besides, in regard to Proposed Soil Framework Directive, Member States and the Candidate Countries of the EU are expected to establish their own national policy by using "the best approaches for soil monitoring and protection" (EU COM, 2006b).

1.2 RISK BASED SOIL QUALITY STANDARDS

Because of its effects on water, air quality, biodiversity and climate change, contaminated soils have to be cleaned-up with regard to the current and future land use type (EU COM, 2006a; EU COM, 2006b). However, soil clean-up brings serious economical burden to governments. Because of economical and technological drawbacks, soil clean-up to background levels is regarded as infeasible in most of the cases. Moreover, the available labor, time, equipment and financial resources to be allocated for remediation of contaminated sites have to be optimized, since it is not possible to overcome all cases simultaneously. Therefore, sites needing remediation should be ranked with respect to their priority. Because of this reason, the approaches, which balance threats on human health and environment with the efforts and funding utilized for remediation, are accepted in most of the countries.

In this respect, risk based approaches are defined by most EU Member States and the North American Countries as the best available strategy for dealing with the problems posed by soil contamination, assessing the need for clean up and planning remedial actions (NICOLE, 2002; US EPA, 2004a). "Risk Assessment in the Federal Government" published by US National Academy of Sciences in 1983 is regarded as the first document that defines the fundamentals for risk based decision making (NICOLE, 2002). Because of the success achieved, the risk based site management approaches have been included in the environmental policy of many countries (NICOLE, 2002).

Risk based decision making basically accounts for source-pathway-receptor analysis. It involves assessment of source characteristics (e.g., source type, size and depth, contaminants of concern and their fate and transport characteristics), site characteristics (e.g., soil, geology, hydrology, climatic conditions, etc.), potential receptors (e.g., human, ecosystem) that could be exposed to contaminants, and the potential exposure pathways (e.g., ingestion, dermal contact, inhalation, etc.) that connect the source to the receptors.

Risk based decision making is used for management of contaminated sites. In this respect, it is utilized for determination and ranking of the sites that need remediation, and setting up clean-up targets for reducing the posed risks to acceptable levels. In most European Countries (e.g., Austria, Belgium, Germany, the Netherlands, United Kingdom (UK), Norway, Sweden, Spain, etc.), Canada and the US, risk based soil quality standards (SQSs) are used to define target levels, to screen sites that do not need further investigation, to determine urgency of remediation or clean-up levels. However, the SQSs used for these purposes are developed with respect to the socio-cultural, political, economical, and environmental conditions of the country.

1.3 SITUATION IN TURKEY

In Turkey, as a candidate country for the EU, for a long time there has been almost no practices towards management of contaminated sites in terms of legal, technical and administrative issues compatible with the EU standards. Soil pollution problems have been regulated by Soil Pollution Control Regulation (SPCR) (MoEF, 2001) until June, 2010. SPCR was first published in 2001, which was then revised with some administrative amendments, to regulate mainly the needs for application of stabilized sludge on soils. Thus, the regulation was providing guidance for these issues and including some pre-specified fixed limiting values for a number of heavy metals that should be allowed in sludge before application on soil. The regulation was also including limiting values for a few number of inorganic and organic substances and soils satisfying these standards were accepted as clean (MoEF, 2005a). However, the upgraded SPCR in force was still not sufficiently qualified in terms of the technical and scientific content. SPCR did not provide a legal definition for contaminated site. A systematic and holistic approach to be followed or the procedures and methods to be applied for the identification, registration, assessment, classification and remediation of contaminated sites were not defined in the regulation. Since the soil quality standards (SQSs) given in the regulation were focusing mainly on the use of stabilized sludge on soil, it was far away from providing common criteria for evaluation of the soil quality. Because of these reasons, the regulation could not been implemented by the Ministry of Environment and Forestry (MoEF) effectively. The environmental pollution problems encountered in Turkey during the recent years resulting from industrial accidents, chemical spills and leakages from storage tanks, illegal waste dumping, and spills from petroleum transfer lines are concrete examples strengthened the need for a comprehensive soil regulation defining the state-of-art for management of contaminated sites.

As a result, need for a new SPCR, which includes a comprehensive management system for contaminated sites and relevant SQSs to be used as a tool for soil quality assessment studies, emerged in order to fulfill the needs of Turkish MoEF. With this purpose, the efforts for development of a management system and the SQSs along the line in EU Thematic Strategy for Soil Protection was initiated in 2006 with the TUBİTAK project titled "Development of an Environmental Management System for Sites Contaminated by Point Sources" (Ünlü et al., 2009). The project was carried out by Middle East Technical University (METU) with the co-operation of the MoEF. The main objective of the project was to develop a systematic approach for identification, registration, assessment, and remediation of contaminated sites and to renew the SPCR by integration of the human health risk based SQSs for priority soil pollutants. After the completion of the project in June 2009, the new regulation on Soil Pollution Control and Sites Contaminated by Point Sources, which includes a comprehensive contaminated sites management system, was published by the MoEF and became legally active as of 8 June 2010. The objectives of this study were drawn up within the context of this project.

1.4 OBJECTIVES AND SCOPE OF THE THESIS

Considering the abovementioned discussions, the major aim of this thesis is to develop *human health risk based SQSs for Turkey* which constitutes one of the most important elements of contaminated sites management system. To achieve this objective a two-phased approach was adopted. Figure 1.1 schematically illustrates the general framework of the study on derivation of human health risk based SQSs for Turkey, the major components of the study, the contents of these components and the interrelations among the components.

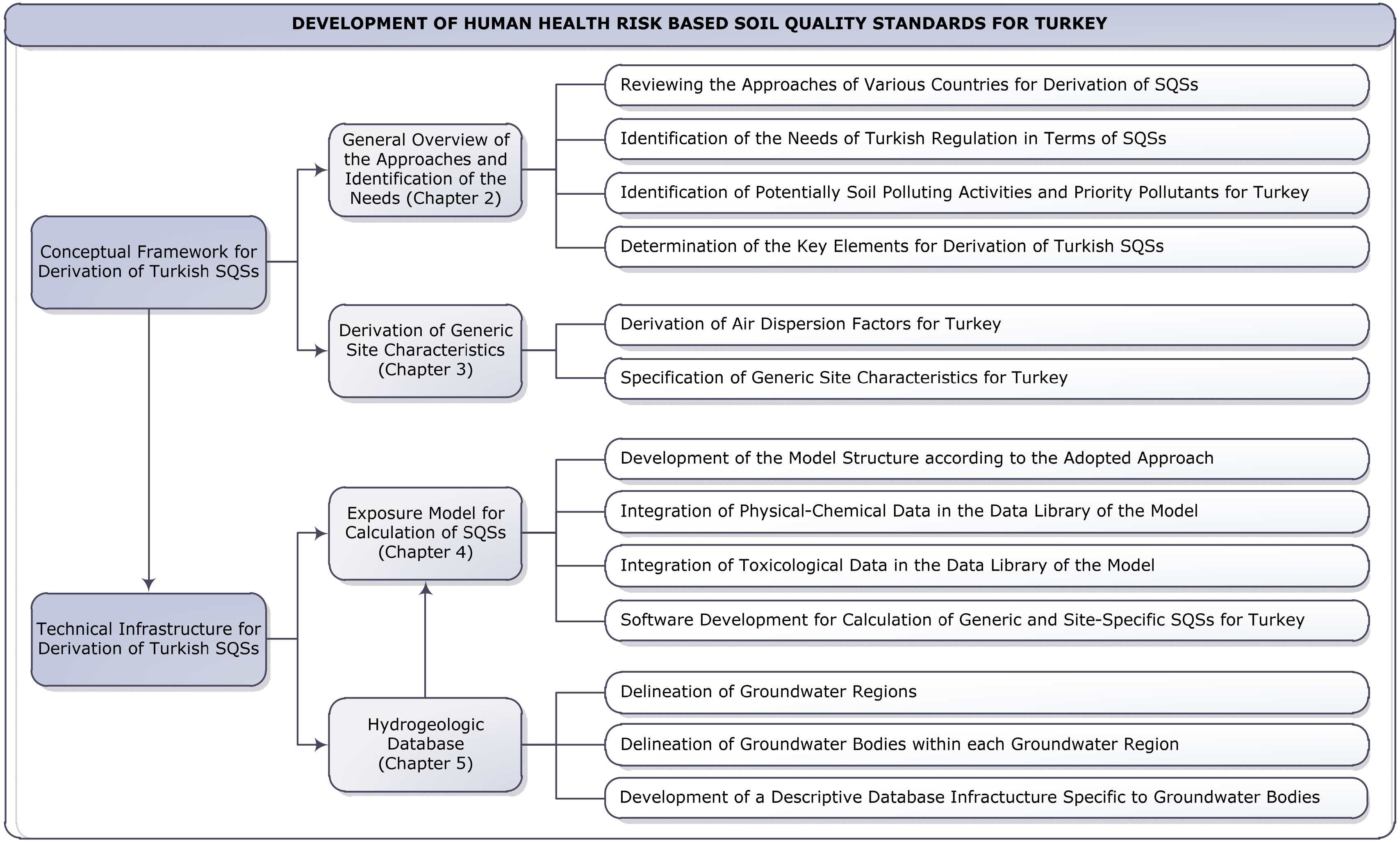


Figure 1.1 Framework of the Study on Developing Human Health Risk Based SQSs for Turkey

The first phase of the study is development of *the conceptual framework* for derivation of Turkish human health risk based SQSs and consists of two tasks. One of these tasks is to draw a general overview of the approaches and identification of the needs for development of risk based SQSs. The main components of this task are determined as (i) reviewing the approaches used by European and North American Countries for development of human health risk based SQSs, (ii) identification of the needs of the new Turkish regulation in terms of SQSs and determination of the role (purpose of use) of the SQSs in the contaminated site management system, (iii) identification of potentially soil contaminating activities in Turkey and the priority soil contaminants that should take place in the new regulation, and (iv) determination of the key elements for derivation of human health risk based SQSs for Turkey.

Since risk based SQSs are developed in conjunction with the country-specific properties, generic site characteristics for Turkey are needed to be derived. In this respect, the second task involves derivation of the air dispersion factors that represent the dispersion of soil contaminant (i.e., volatiles and fugitive dusts) emissions in air under regional meteorological conditions and specification of the site characteristics that control generation of fugitive dust emissions.

On the other hand, the derivation of human health risk based SQSs involves use of a large amount of information and data, which are progressively subject to changes or upgrades. SQSs derivation process is very dynamic in nature, because SQSs are sensitive to changes in

- exposure parameters and contact rates that differ with respect to the exposure scenario and receptors of concern,
- generic site characteristics with respect to soil, hydrogeologic and climatic conditions,
- physical-chemical and toxicological properties of contaminants, which are periodically upgraded or newly produced through recent scientific research.

Therefore, to maintain the sustainability and currency of generic and site-specific SQSs, the improvements in the toxicological and other scientific research should be monitored continuously and SQSs should be upgraded with the use of latest information or data produced.

Consequently, the second phase of this study aims developing the *technical infrastructure for derivation of Turkish human health risk based SQSs* that ensures the sustainability, maintenance and dynamism of the Turkish contaminated sites management system. One specific task to achieve this objective is development of a computational tool (called exposure model), which includes the physical-chemical and toxicological data libraries embedded in its structure, to facilitate calculation of generic and site-specific SQSs and to eliminate the potential calculation mistakes that may result due to various parameter values and chemical-specific data used in calculations.

On the other hand, generic and site-specific risk assessment entails a comprehensive understanding of the soil and hydrogeological (groundwater) conditions at contaminated sites (URL 1). These conditions are significant for determination of the generic site characteristics to be used in calculation of generic SQSs, calculation of site-specific SQSs, assessment of the dilution conditions as contaminants leach from soil to groundwater, development of pertinent conceptual site models (CSMs) during site assessment studies, characterization of site conditions and development of accurate sampling strategies.

In this regard, another task to strengthen the technical infrastructure is development of a Geographical Information Systems (GIS) based hydrogeological database (HGDB) which includes the general soil and hydrogeologic characteristics of a site needed for human health risk assessment studies. The sub-tasks for development of the HGDB involves delineation of the basic hierarchic mapping and management units (i.e., groundwater regions, and groundwater bodies within each groundwater region) that enables collecting easily manageable hydrogeological data at both regional and local scales in a systematic manner, and development of the descriptive infrastructure of the database specific to each groundwater body within a region.

In order to achieve the overall objective, a two-phased approach was proposed. However, the additional aims of this thesis can be summarized as to give a perspective for derivation of human health risk based SQSs, to identify the components of this derivation procedure, to point out the data gaps in Turkey for conducting risk assessment studies and the potential study areas to fulfill these gaps.

1.5 NOVELTY AND CONTRIBUTION OF THIS THESIS

Risk based approach to contaminated sites is a relatively new subject for Turkey. Turkish human health risk based SQSs were developed, for the first time, by integration of the country specific characteristics. Moreover, the results of the study may guide and aid MoEF in setting the standards in the new regulation on Soil Pollution Control and Sites Contaminated with Point Sources (MoEF, 2010). In this regard, by its contribution to the regulatory system, this thesis makes contribution to contaminated site management in Turkey.

Another national contribution of this thesis is the derivation of generic air dispersion factors for Turkey, which are required and essential for estimation of inhalation exposures to soil contaminants. For this purpose an air dispersion model was run by use of 7 years of hourly meteorological data (i.e., surface observations and upper air soundings including vertical profiles of temperature, relative humidity, wind direction and speed) for the seven meteorological stations in Turkey which record radiosonde data.

Although many exposure models are available both in Europe and the US for estimation of risk based limit values, because they are based on different approaches (use of different assumptions, generic values and terminologies), most of the time it is difficult and may not be straight forward to calculate Turkish SQSs. In the developed model, the equations used for calculation of SQSs, generic values for exposure parameters and site characteristics, physical-chemical and toxicological data used in calculations are all integrated with the computational tool. This tool allows changes in parameter values and chemical specific data, in turn, updating risk based SQSs that may be deemed necessary in the future. Being the first exposure model developed with respect to the approach adopted for derivation of Turkish SQSs, the study contributes to contaminated site risk assessment works conducted by the regulatory authorities and the other stakeholders.

Finally, this study developed a unique HDGB which delineates groundwater regions and groundwater bodies for contaminated sites management system in Turkey. Besides, this HGDB forms the first steps to fulfill the requirement stipulated by EU Water Framework Directive (WFD) (EU COM, 2000) for identification of groundwater bodies which is considered as a tool to describe the quantitative and chemical status of groundwater systems.

1.6 ORGANIZATION OF THE THESIS

The thesis is organized in six chapters. The main subjects of the thesis are presented in different chapters. In order to maintain the coherence and to preserve the integrity, the pertinent literature review, the methodology and the results for each subject are presented together in the same chapter.

In Chapter 2, the theoretical background and the overview of the approaches used in various European Countries, Canada and the US for derivation of human health risk based SQSs are given. Considering the review of the current approaches, the methodology adopted and used for derivation of Turkish human health risk based SQSs are described and the results of the study are presented.

In Chapter 3, the theoretical background and the studies performed for development of the generic and site-specific air dispersion factors and generic site characteristics controlling the amount of fugitive dust emissions, which are essential to calculate Turkish SQSs for inhalation of volatiles and fugitive dusts, are described and the results of the study are presented.

In Chapter 4, the most common exposure models used in Europe and the US for calculation of generic and site-specific SQSs are described. The studies performed for development of an exposure model that would be used for calculation of generic and site-specific SQSs for Turkey are explained. The features of this model are introduced and the results are presented.

In Chapter 5, the theoretical background for development of a HGDB and delineation of hydrogeologic units, which forms the basis for data storage, are described. The methodology used for delineation of the hydrogeologic units (i.e., groundwater regions and groundwater bodies) and development of a descriptive database infrastructure specific to groundwater bodies, which are the essential components for development of a HGDB for Turkey, are explained. The results of the study are presented accordingly.

Finally, in Chapter 6 the conclusions of the study and recommendations for future studies are presented.

CHAPTER 2

SOIL QUALITY STANDARDS

2.1 THEORETICAL BACKGROUND

Soil Quality Standards (SQSs) are scientifically based generic assessment criteria, which represent “the conservative conditions broadly applicable for a range of sites” (US EPA, 1989). SQSs are used for evaluating long term risks to human health and/or environment. Thus, they constitute the essential component of any soil contamination policy. Since SQSs are derived by considering the potential risks posed to the receptors, they serve as a tool for assessment of soil quality and facilitate making decisions, thus can lead to “important savings of money and time” (Ferguson et al., 1998).

In this study, human health risk based SQSs are considered. In the following sections, the fundamentals for derivation of human health risk based SQSs (Section 2.1.1) are discussed, as well as the approaches of various countries towards derivation of the standards (Section 2.1.2).

2.1.1 The Fundamentals of Human Health Risk Based SQSs

For development of human health risk based SQSs, adverse health effects resulting from exposure to soil contaminants through various pathways are taken into consideration. Human health risk based SQSs designate concentrations of contaminants in soil “at or below which no appreciable human health risk is expected” (CCME, 1999).

Development of SQSs entails a comprehensive review of the physical characteristics of the environment, environmental fate and transport characteristics of contaminants, potential exposure pathways and receptors of concern, and toxicological properties of contaminants. In the following sub-sections, these issues are discussed step by step.

2.1.1.1 Generic Site Characteristics

The physical characteristics of the contaminated site are important for risk assessment studies (US EPA, 1989). Consequently, the regional characteristics of a country are important for development of national SQSs. The general site characteristics that are representative of the country and conservative for any site conditions are considered as for development of generic SQSs. The general site characteristics important for development of SQSs include:

- climate and meteorology (e.g., temperature, precipitation, wind speed and direction),
- soil characteristics (e.g., soil texture, soil organic carbon content, etc.),
- vegetation properties
- geologic and hydrogeologic setting (US EPA, 1989).

2.1.1.2 Fate and Transport of Contaminants

Development of risk based SQSs is based on the source-pathway-receptor relationship. The fate and transport of contaminants in the environmental media (air, water and soil) determine the effective exposure pathways that connect the source of contamination to the receptor (Figure 2.1). Once contaminants are released into the environment, they might be transported through soil, groundwater, surface water, air or dusts, and absorbed by plants, etc. (Ferguson et al., 1998). Besides, contaminants might be accumulated in one or more media (including the receiving medium) (US EPA, 1989) or undergo

- physical transformations (e.g., volatilization, precipitation),
- chemical transformations (e.g., photolysis, hydrolysis, oxidation, reduction, etc.), and/or
- biological transformations (e.g., biodegradation) (Ferguson et al., 1998; US EPA, 1989).

All these processes affect the toxicity, availability and mobility of a contaminant, thus the risk posed by the contaminant.

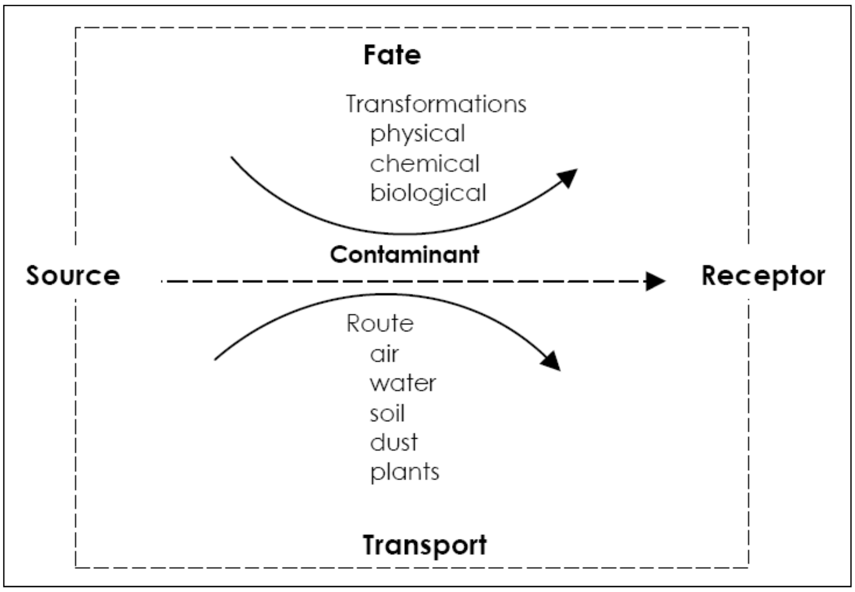


Figure 2.1 Fate and Transport of Contaminants in Soil (Ferguson et al., 1998)

Receptors might be exposed to contaminants either directly or indirectly. Soil ingestion, soil dermal contact, and inhalation of soil particulate can be listed among direct exposure pathways (CCME, 1999; Swartjes, 2004). On the other hand, consumption of contaminated crops, meat and milk, consumption of fish, etc. are considered as indirect exposure pathways (CCME, 1999; US EPA, 1989). The potential pathways that a human might be exposed to are illustrated in Figure 2.2.

Therefore, environmental fate and transport properties of chemicals are important to predict chemical concentrations in different environmental mediums and human exposure through potential pathways. In order to estimate the fate and transport of the chemicals at a particular site, information on physical-chemical properties of contaminants are need to be known. In Table 2.1, important physical-chemical and environmental fate parameters and their significance are summarized. These physico-chemical properties are also needed during risk assessment studies and for derivation of SQSs.

Computer databases, such as EPI Suite, MEPAS, MULTIMED, RESRAD, GENII, SRC's Environmental Fate, CHEMFATE, and BIODEG databases; BIOSIS and AQUIRE may be used as sources for up to date information on the physical-chemical properties of the chemicals of concern (US EPA, 1989; Whelan, 1997).

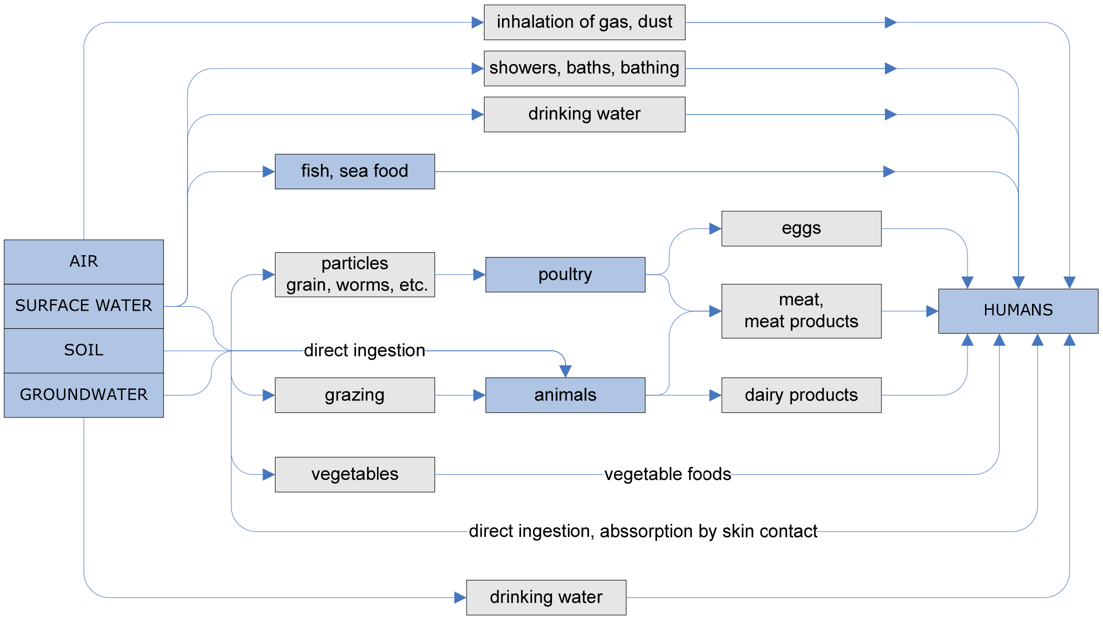


Figure 2.2 Humans Exposure Routes for Contaminants (UNEP, 2005)

Table 2.1 Important Physico-Chemical and Environmental Fate Parameters (US EPA, 1989)

Parameters	**Significance**
K_{oc}	provides a chemical specific measure of the extent of chemical partitioning between organic carbon and water at equilibrium. The higher the K_{oc}, the more likely a chemical is to bind to soil or sediment than to remain in water.
K_d	provides a soil or sediment-specific measure of the extent of chemical partitioning between soil or sediment and water, unadjusted for dependence upon organic carbon. To adjust for the fraction of organic carbon present in soil or sediment (f_{oc}), use $K_d = K_{oc} \times f_{oc}$. The higher the K_d, the more likely a chemical is to bind to soil or sediment than to remain in water.
K_{ow}	provides a measure of the extent of chemical partitioning between water and octanol at equilibrium. The greater the K_{ow}, the more likely a chemical is to partition to octanol than to remain in water. Octanol is used as a surrogate for lipids (fat), and K_{ow} can be used to predict bioconcentration in aquatic organisms.
Solubility	is an upper limit on a chemical's dissolved concentration in water at a specified temperature. Aqueous concentrations in excess of solubility may indicate sorption onto sediments, the presence of solubilizing chemicals such as solvents, or the presence of a non-aqueous phase liquid.
Henry's Law Constant	provides a measure of the extent of chemical partitioning between air and water at equilibrium. The higher the Henry's Law constant, the more likely a chemical is volatilize than to remain in water.

Table 2.1 Important Physico-Chemical and Environmental Fate Parameters (cont'd)

Parameters	**Significance**
Vapor Pressure	is the pressure exerted by a chemical vapor in equilibrium with its solid or liquid form at any given temperature. It is used to calculate the rate of volatilization of pure substance from a surface or in estimating a Henry's Law constant for chemicals with low water solubility. The higher the vapor pressure, the more likely a chemical is to exist in a gaseous state.
Diffusivity	describes the movement of a molecule in a liquid or gas medium as a result of differences in concentration. It is used to calculate the dispersive component of chemical transport. The higher the diffusivity, the more likely a chemical is to move in response to concentration gradients.
Bioconcentration Factor (BCF)	provides a measure of the extent of chemical partitioning at equilibrium between a biological medium such as fish tissue or plant tissue and an external medium such as water. The higher the BCF, the greater the accumulation in living tissue is likely to be.
Media-specific Half-life	provides a relative measure of the persistence of a chemical in a given medium, although actual values can vary greatly depending on site-specific conditions. The greater the half-life, the more persistent a chemical is likely to be.

2.1.1.3 Toxicological Properties

As mentioned previously, risk based SQSs are derived based on the potential risks posed by contaminants to the receptors of concern. These potential risks are related with the toxicity of contaminants. Toxic substances result in adverse health effects and these effects are quantified by integration of toxicity data to risk assessment (US EPA, 1989).

Toxicity, in other words safe exposure levels for chemicals, is determined through a series of laboratory experiments on animals or epidemiological studies on human populations (DEFRA, 2006; CCME, 1999). Toxicity assessment is mainly composed of *(i) hazard identification*, and *(ii) dose respond assessment* (US EPA, 1989). Hazard identification gives information about "the potential adverse effects (e.g., cancer, birth defect) of the chemicals on the receptors", whereas dose response assessment describes "the relationship between the magnitude of the exposure from different exposure routes and the probability of the occurrence of these adverse effects in the receptors" (Li-Muller, 1996; CCME, 1999).

In terms of adverse health effects that they pose, contaminants can be categorized as threshold chemicals (non-carcinogens) or non-threshold chemicals (carcinogens) (Swartjes, 2004). Threshold chemicals do not produce any observable adverse health effects below threshold dose that is "the amount of contaminant to which a person can be exposed daily over a lifetime without appreciable health risks" (DEFRA, 2002a). Threshold dose is represented by "*reference dose (RfD)*", which is expressed in terms of mass of substance per kg body weight over a period of time (mg/kg-day) (US EPA, 1989). For threshold substances (e.g., lead, toluene, aliphatic petroleum hydrocarbons), "exposure less than the reference dose pose zero probability of incidence of an adverse health effect" (US EPA, 2002a). On the other hand, for non-threshold chemicals (i.e., carcinogens such as arsenic, benzene, benzo[a]pyrene) even the lowest exposure to contaminant results in an increased chance of an individual developing cancer over a lifetime (US EPA, 1989). The critical risk specific dose is represented by "*cancer slope factor* (*SF*)" which represents the cancer risk associated with a unit dose of a carcinogenic contaminant and expressed as $(\text{mg/kg-day})^{-1}$ (US EPA, 1989).

If critical exposure doses for threshold and/or non-threshold substances are exceeded, adverse health effects are expected to occur (US EPA, 1989). In this respect, adopting toxicity assessments of reputable regulatory agencies is important for determining the safe exposure levels (Li-Muller, 1996). The toxicity data produced by various international sources are presented in Appendix-A. However, it should be noted that toxicological data are produced in compliance with the equations used for derivation of SQSs. Therefore, it is very important to use the toxicological data that are compatible with the derivation methodology (URL 6).

2.1.1.4 Quantification of Risks

In general, risk is defined as "the function of probability and the consequence of an undesirable event" (SFT, 1999; Li-Muller, 1996) and can be described by

$$Risk = Exposure \times Severity\ of\ Event\ (Hazard) \tag{2.1}$$

When assessing the human health risks posed by a contaminated site, the following items are taken into consideration;

- potential pathways that might result in human exposure,
- exposure concentrations of contaminants and the frequency of exposure, and
- assessment of adverse health effects in case of exposure (dose/response relationship) (SFT, 1999).

These items are considered together within pathway-specific equations used to calculate cancer risks and non-cancer hazard quotient. The general forms of these equations are given below.

For carcinogenic effects: Carcinogenic risks are estimated as "the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (i.e., incremental or excess individual lifetime cancer risk)" (US EPA, 1989). To calculate cancer risk, chronic daily intake (*CDI*) of a contaminant [mg/kg-d]; and the slope factor (*SF*) [$(\text{mg/kg-d})^{-1}$] are used (see Equation 2.2). Hence, the safe exposure levels (i.e., soil quality criteria) to non-threshold substances are back-calculated from this equation for a pre-accepted risk level which ranges from 10^{-6} to 10^{-4} (1 incident in a million to 1 incident in a ten thousand of population) (US EPA, 2002a).

$$Cancer\ Risk = CDI \times SF \tag{2.2}$$

For non-carcinogenic effects: Non-carcinogenic effects are evaluated by "comparing an exposure level over a specified time period with a reference dose derived for a similar exposure period" (US EPA, 1989). To describe this comparison, "*hazard quotient"*, which is the ratio of chronic daily intake (*CDI*) of a contaminant [mg/kg-d] to reference dose (*RfD*) for that substance [mg/kg-d], is used. If hazard quotient exceeds unity "1", non-cancer health effects may be observed. Oppositely, no adverse health effects are expected even for sensitive populations (e.g. children) below unity. Thus, the safe exposure levels (i.e., soil quality criteria) to threshold substances are back-calculated using this relation.

$$Hazard\ Quotient = \frac{CDI}{RfD} \tag{2.3}$$

While calculating human health risk based soil quality criteria, human exposure to soil contaminants through various exposure pathways (e.g. soil ingestion) are considered. In this respect, Equations 2.2 and 2.3 form the basis for development of pathway-specific equations for calculation of human health soil quality criteria. Receptor characteristics, exposure rates, and site characteristics, which define human exposure rate to soil contaminants, are also integrated to these pathway-specific equations as appropriate. The general form of the equation representing the exposure to soil contaminants is shown as follows (US EPA, 1989):

$$CDI = \frac{C \times ER \times EF \times ED}{BW \times AT} \tag{2.4}$$

where C is the chemical concentration in soil [mg/kg]; ER is the chemical exposure rate [mg soil/day]; EF is the exposure frequency [days/year]; ED is the exposure duration [years]; BW is the body weight [kg]; and AT is the averaging time (period over which exposure is averaged) [days]. Hence, soil quality criteria are derived by back-calculating the chemical concentration in soil (C). Consequently, the calculated soil quality criteria represent the concentration levels in soil that may pose adverse health effects in case exceeded.

2.1.1.5 Perception of Risk

As mentioned before, soil quality criteria for non-threshold substances are calculated based on a target (acceptable) risk level. However, in various countries, different target risk levels have been accepted. Actually, target risk level does not only designate the perception of risk, but also a political decision made by authoritative bodies. Since SQSs are derived depending on the target risk level, the number of sites that are considered to be polluted depends on the target risk level defined. On account of that, it affects the financial sources allocated for assessment and/or remediation of a site.

Table 2.2 given below summarizes the risk levels accepted by several organizations/countries. Besides, Table 2.3 is presented to give "a sense of scale for people's perception of the probability of any particular adverse event happening" (DEFRA, 2006).

Table 2.2 Accepted Risk Levels by Different Organizations/Countries (DEFRA, 2006)

Organization/ Country	**Context**	**Tolerable Risk**
WHO	Guidelines for Drinking Water Quality	10^{-5}
EU	Drinking Water Standards	10^{-6}
US EPA	Soil Screening Levels	10^{-6} (10^{-4} for additive risks)
RIVM	Dutch Intervention Values for Soil	10^{-4}
Norway	General	10^{-5}
Germany	General	10^{-5} ($5x10^{-5}$ for additive risks)

Table 2.3 Qualitative Descriptions of Probabilities (DEFRA, 2006)

Probability of Event Happening	**Qualitative Description**	**Real Example (probability of event in any one year)**
Less than 1 in 10^{6}	Negligible	Being hit by lightning
Less than 1 in 10^{5}	Minimal	
Less than 1 in 10^{4}	Very low	Dying from leukaemia, or from playing soccer, or in an accident at home
Less than 1 in 10^{3}	Low	
Less than 1 in 10^{2}	Moderate	Death aged 40 from natural causes
More than 1 in 10^{2}	High	

2.1.2 Overview of the Soil Quality Standards

In order to confront the environmental and health problems associated with soil contamination, EU proposed the Member States and the candidate countries to reconfigure their soil policy by including the best approaches for soil protection (EU COM, 2006b). In this respect, many EU countries have developed or renewed their policies and adopted risk based approaches. Some of the countries inspired from the other European countries’ approaches while developing their soil quality criteria (Carlon et al., 2007). The European Commission Technical Guidance Document on Risk Assessment (ECB, 2003), the approaches of RIVM, the USA (e.g., ASTM, 1998), the former Soviet Union and Canadian Guidelines

(CCME, 1999) (especially for ecological risk assessment) are among the main references utilized by the new EU Member States for development of risk based soil quality criteria (Carlon et al., 2007).

With regard to EU requirements, Turkish regulations on soil protection were reviewed from past to present and the deficiencies of the SPCR was identified (Section 2.1.2.1). The SQSs of the countries leading in risk assessment of contaminated lands were reviewed. Due to their experiences in management of contaminated sites and the availability of detailed information, the SQSs of the USA, Germany, Netherlands, and Canada are discussed in detail (from Section 2.1.2.2 to 2.1.2.5). In addition, the approach of Norway, which is relatively (SFT, 1995), was also examined in detail (Section 2.1.2.6). Besides, the similarities and distinctions between the approaches of several other countries (e.g., Austria, Belgium, Czech Republic, Denmark, Finland, France, Italy, Lithuania, Poland, Slovak Republic, Spain, Sweden, and the United Kingdom) for development of SQSs are pointed out (Section 2.1.2.7).

2.1.2.1 Turkish Regulations on Soil Pollution Control

In Turkey, as a candidate country for the EU, for a long time there has been almost no practices towards management of contaminated sites in terms of legal, technical and administrative issues compatible with the EU standards. Until 2001, the two pioneering regulations stemming from the Environmental Law of 1983, namely Solid Waste Control Regulation (14.3.1991-20814; amendment 05.04.2005-25777) and Hazardous Waste Control Regulation (27.08.1995-22387; amendment 14.03.2005-25755) were referring to the prevention of soil pollution resulting from improper waste management activities. In 2001, the Soil Pollution Control Regulation (SPCR) was first published to regulate mainly the needs for application of stabilized sludge and composts on soils. In 2005, the regulation was updated by some administrative arrangements (MoEF, 2005a). The regulation was including some pre-specified fixed limiting values for a few number of inorganic and organic substances (see Table 2.4 and Table 2.5). According to the regulation, soils satisfying these standards were accepted as clean. Otherwise, any contaminated site had to be remediated up to these levels. In other words, the standards set by the regulation were in use both for identification of soil contamination and as the clean-up levels, regardless of the site-specific conditions.

Table 2.4 Turkish SQSs for Heavy Metals (MoEF, 2005a)

Heavy Metals (Total)	**pH 5-6** ∗∗ **mg/kg of dry soil**	**pH** > **6** ∗∗ **mg/kg of dry soil**
Lead	50	300
Cadmium	1	3
Chromium	100	100
Copper ∗	50	140
Nickel ∗	30	75
Zinc ∗	150	300
Mercury	1	1.5

∗ If pH is greater than 7, the Ministry may increase the standards up to 50% provided that no adverse effect to environment and human health, especially to groundwater, is expected.

∗∗ These standards may be exceeded at cultivated lands used for animal feeding if it is proved by scientific studies that there exists no hazardous effect to environment and human health.

Table 2.5 Turkish SQSs to be satisfied After Remediation (MoEF, 2005a)

Contaminants	**Limit Values (mg/kg of dry soil)**	**Contaminants**	**Limit Values (mg/kg of dry soil)**
Chloride (Total) ∗	25	Toluene	0.05
Sodium (Total) ∗	125	Xylene	0.05
Cobalt	20	Phenol	0.05
Arsenic	20	Selenium	5
Molybdenum	10	Thallium	1
Tin	20	Uranium	5
Barium	200	PAHs	5
Fluoride	200	Organochlorides	0.5
Free cyanide	1	Pesticides – Individual	0.5
Complex cyanide	5	Pesticides – Total	2
Sulphide	2	Polychlorinated Biphenyls	0.5
Bromide	20	Hexachlorobenzene	0.1
Benzene	0.05	Pentachlorobenzene	0.1
Butyl benzene	0.05	Ψ- HCH (lindane)	0.1

∗ in terms of mg/L

The regulation was also including standards for a number of heavy metals that should be allowed in sludge before application on soil (see Table 2.6). As a result, the upgraded SPCR in force was still not sufficiently qualified in terms of technical and scientific content and it was lacking the insight of the latest risk based approaches for contaminated site management. SPCR were not even providing a legal definition for contaminated sites. Although the SPCR was pointing out the importance of protecting soil against pollution, and the need for confinement, investigation, monitoring and remediation of soils contaminated as a result of industrial activities and accidents, a systematic and holistic approach to be followed or the procedures and methods to be applied for the identification, registration, assessment, classification and remediation of contaminated sites were not defined in the regulation.

Table 2.6 Turkish SQSs for Maximum Heavy Metal Concentrations for Application of the Stabilized Sludge on Soil (MoEF, 2005a)

Heavy Metals (Total)	**Limit Values (mg/kg of dry soil)**
Lead	1200
Cadmium	40
Chromium	1200
Copper	1750
Nickel	400
Zinc	4000
Mercury	25

As a result, need for a new SPCR, which includes a comprehensive management system for contaminated sites and relevant SQSs to be used as a tool for soil quality assessment studies, emerged in order to fulfill the needs of Turkish MoEF. With this purpose, the efforts for development of a management system and the SQSs along the line in EU Thematic Strategy for Soil Protection was initiated in 2006 with the TUBİTAK project titled "Development of an Environmental Management System for Sites Contaminated by Point Sources" (Ünlü et al., 2009). The project was carried out by Middle East Technical University (METU) with the co-operation of the MoEF. The main objective of the project was to develop a systematic approach for identification, registration, assessment, and remediation of contaminated sites and to renew the SPCR by integration of the human health risk based SQSs for priority soil pollutants. After the completion of the project in June 2009, the new regulation on Soil Pollution Control and Sites Contaminated by Point Sources, which includes a comprehensive contaminated sites management system, was published by the MoEF and became legally active as of 8 June 2010.

2.1.2.2 The United States of America

The US Environmental Protection Agency (EPA) is one of the organizations leading in risk assessment studies. US EPA conducting risk assessment studies since the 1970s. To standardize the evaluation of contaminated sites, US EPA has published Soil Screening Guidance (SSG) (US EPA, 1996c), which presents the methodology to calculate risk based soil screening levels (SSLs) for soil contaminants. Following that, many ancillary documents and reports were produced by US EPA to describe the background and requirements for development of site-specific soil quality criteria. Although human health risk is the main subject discussed in the US EPA documents, US EPA (2002a) mentions about the significance of ecological risk assessment. Thus, EPA is currently developing generic ecological SSLs for chemicals that have primary importance from ecological point of view (US EPA, 2002a).

US EPA provides a look-up table, which includes the generic human health SSLs derived for commonly observed soil contaminants at National Priority List (NPL) sites (US EPA, 1996a, US EPA, 2002a). In order to be conservative for a broad range of site conditions, a generic exposure scenario is assumed for development of SSLs (US EPA, 2002a). Future residential land use assumption (and related exposure scenarios), which is the simplest and less site-specific but conservative, is adopted for development of SSLs (US EPA, 1996c, US EPA, 2002a). Since generic SSLs do not handle all human exposure pathways, the current exposure pathways at a site are need to be compared with the pathways considered within the generic scenario before using generic SSLs (US EPA, 1996a). In Supplemental Guidance document (US EPA, 2002a), SSLs for 109 chemicals are presented for the following scenarios:

- residential scenario,
- commercial/industrial scenario: outdoor worker, and
- commercial/industrial scenario: indoor worker.

The look-up tables developed for each of these scenarios include the information given in Table 2.7. Although inhalation of volatiles in indoor air is considered as a potential exposure pathway for residential receptors and indoor worker receptors, generic SSLs have not been calculated by EPA because of the difficulty in setting appropriate generic values for inputs such as "dimensions of commercial buildings and the distance between contamination and a building's foundation" (US EPA, 2002a).

Table 2.7. The Content of the Generic SSLs Look-up Table

Compound	Cas No.	Ingestion-Dermal (mg/kg)	Inhalation of Volatiles (outdoor) (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Groundwater	
					DAF = 20 (mg/kg)	DAF = 1 (mg/kg)

Target risk level accepted by US EPA is one-in-a-million ($1x10^{-6}$) excess lifetime cancer risk for carcinogens and a hazard quotient (*HQ*) of one for non-carcinogens (US EPA, 2002a). The additive effects of the chemicals are not included in the SSLs (US EPA, 1996a). For carcinogens, EPA believes that "10^{-6} risk level for individual chemicals will generally lead to cumulative risks within the risk range 10^{-4} to 10^{-6} for combination of chemicals" (US EPA, 1996a). For non-carcinogens, EPA (US EPA, 1996a) states that additive risks should be considered only for the chemicals that have the same toxic effects.

As the name implies, SSLs are used as a screening tool for identification of areas that do not require further attention (US EPA, 1996b). On the other hand, SSLs are not regarded as national cleanup levels (US EPA, 1996b). The place of SSLs in the scale of contaminant concentrations, which is used in identifying and managing risks at sites, is given in Figure 2.3, and the decisions taken by use of SSLs are listed in Table 2.8.

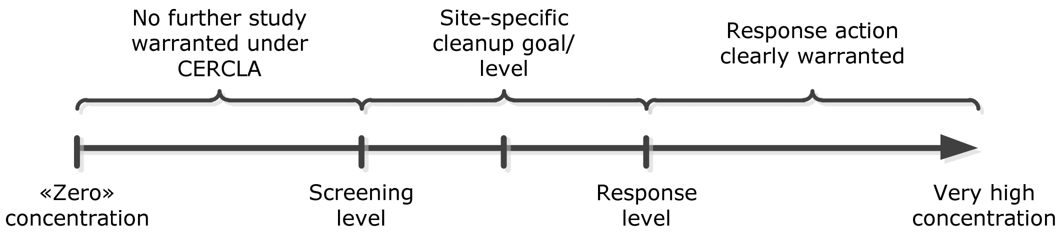


Figure 2.3. Conceptual Risk Management Scale for Contaminated Soil (US EPA, 1996b)

Table 2.8. Decisions Taken in the US according to Contaminant Concentrations in Soil

CONDITION	DECISION
Contaminant concentration < SSLs	No further action under CERCLA*
Contaminant concentration ≥ SSLs	Further investigation (but not necessarily cleanup)

* "CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act), commonly known as Superfund, was created to protect people, families, communities and others from heavily contaminated toxic waste sites that have been abandoned".

SSLs for the migration to ground water pathway are back-calculated from the following acceptable groundwater concentration standards: "non-zero maximum contaminant level goals (MCLGs); maximum contaminant levels (MCLs); or health-based limits (based on a cancer risk of 1×10^{-6} or an *HQ* of one)" (US EPA, 2002a). While calculating the SSLs for this pathway a dilution attenuation factor (*DAF*) is considered. A *DAF* of 20 accounts for "reductions in contaminant concentration due to natural processes occurring in the subsurface" (US EPA, 2002a). On the other hand, a *DAF* of one is assumed where "no dilution or attenuation between the source and the receptor well is expected at a site (e.g., sites with shallow water tables, fractured media, karst topography, or source size greater than 12.1ha (30 acres))" (US EPA, 2002a; US EPA, 1996a).

2.1.2.3 Canada

The Canadian Council of Ministers of the Environment (CCME) published "A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines" in 1996 (CCME, 2006) and Canadian soil quality guidelines (SQG) have been developed based on this protocol. Canadian SQGs indicate "clean down to levels" at contaminated sites and not "pollute up to levels" for less contaminated sites (CCME, 2006). However, the guideline values cannot be used for assessing the quality of soil by application of compost and fertilizers on soil (CCME, 2006).

For derivation of Canadian SQGs the protection of ecological and human receptors are considered. The SQGs are developed based on "four land use scenarios; agricultural, residential/parkland, commercial, and industrial land uses" (CCME, 1996).

For determination of the human health SQGs, "direct soil exposure (soil ingestion, dermal contact, and particulate inhalation), transport of contaminants through groundwater to potential potable water sources, intrusion of contaminant vapors into buildings, and human consumption of contaminated food pathways" are considered (CCME, 2006) and the lowest concentration is considered as the SQG for human health. Different from the other countries' approaches, "estimated daily intake (EDI) of a chemical due to background exposure (unrelated to the contaminated site)" is also considered for derivation of human health SQGs (CCME, 2006). The environmental and human health SQG values are calculated separately and the lowest of these values is determined as the final SQG. Final SQG for a list of compounds are presented in a look-up table like given in Table 2.9.

Table 2.9 The Structure of Canadian SQSs Look-up Table

Compounds	Land Use			
	Agricultural	Residential/ Parkland	Commercial	Industrial

Similar to US EPA approach, generic SQGs for migration to groundwater pathway is derived by assuming that "the soil is in contact with the groundwater, and a potable water well could be installed at the edge of the contaminated site" (CCME, 2006). A generic dilution factor (*DF*) of 50 is used to account for the dilution in the pore water draining to groundwater (CCME 1996).

2.1.2.4 Germany

In Germany, the issues related with soil contamination are managed by use of the Federal Soil Protection Act that was put into force in 1999 (Ferguson, 1999a). The Federal Soil Protection and Contaminated Sites Ordinance constitutes the main elements of the contaminated site management system.

Similar to US EPA, SQSs of Germany are based on pathways and land use types. SQSs are developed by risk based approaches as action and trigger values for the pathways and land use types defined in Table 2.10 (Federal Ministry of

Environment, 1999a and 1999b). These soil quality criteria are derived based on the acceptable risk level of 10^{-5} for individual carcinogenic chemicals (Ferguson et al., 1998). According to the SQSs given in Federal Ordinance on Soil Protection and Contaminated Sites, the decisions summarized in Table 2.11 can be taken (Federal Ministry of Environment, 1999a).

Table 2.10 The Structure of German SQSs Look-up Table (Federal Ministry of Environment, 1999a)

Pathway	Land Use	SQSs
Soil - Human Health Pathway (Direct Contact)	Playgrounds Residential Areas Parks and Recreation Facilities Industrial and Commercial Areas	Action and Trigger Values
Soil - Plant Pathway	Agriculture Vegetable Garden Grassland	Action and Trigger Values
Soil - Groundwater Pathway	-	Trigger Value

Table 2.11. Decisions Taken according to Contaminant Concentrations in Soil in Germany

CONDITION	DECISION
Contaminant Concentration < Trigger Values	The suspicion of soil degradation is deemed unfounded
Contaminant Concentration > Trigger Values	Further investigation is required taking the relevant soil use into account to identify any soil degradation or site contamination
Contaminant Concentration > Action Values	Signal for the presence of soil degradation or site contamination Measures are required by taking the relevant soil use into account

In addition to action and trigger values, precautionary values are developed for prevention of soil contamination (Federal Ministry of Environment, 2002). The precautionary values consider "the protection of the soil functions in the case of sensitive uses" (Federal Ministry of Environment, 1999a). In Annex 2 of the Ordinance precautionary values for metals (cadmium, lead, chromium, copper, mercury, nickel and zinc) and organic substances are given. The precautionary values are differentiated by the main soil types (see Table 2.12) in conjunction with "the Pedological Mapping Guide" (Federal Ministry of Environment, 1999a; Federal Ministry of Environment, 2002). Precautionary values are based on "ecotoxicological thresholds, taking into account ubiquitous and natural background levels" (Federal Ministry of Environment, 1999a).

Table 2.12. The Precautionary Values

Precautionary Values				
Metals			**Organics**	
Clay	Loam/Silt	Sand	Humus content > 8%	Humus content ≤ 8%

2.1.2.5 The Netherlands

In the Netherlands, soil clean-up operations started in the 1980s. The scientific background for the soil quality objectives and risk assessment procedures are provided by the National Institute of Public Health and Environmental Protection (RIVM) (Ferguson, 1999a). The Ministry of Housing, Spatial Planning and the Environment (VROM, 2000) decides on the general soil policy.

In the Netherlands, two generic risk based standards are used; target values and intervention values. The target value is based on potential risks to ecosystems, while the intervention value is based on potential risks to humans and ecosystems. In addition, the intermediate value, which is the average of target and intervention values, is used for classification of soil and groundwater as "clean, slightly contaminated or seriously contaminated". The details about this classification is given in Table 2.13 and exhibited in Figure 2.4.

In the Netherlands, soil quality criteria are derived based on 10^{-4} risk level and are corrected with respect to the organic matter and clay content of soil (Swartjes, 2004; Ferguson, 1999a). Besides, the intervention value for groundwater is calculated based on a dilution factor of 10 (Swartjes, 2004).

Table 2.13. Decisions taken according to Contaminant Concentration Level in Soil in the Netherlands

CONDITION	CLASSIFICATION	DECISION
Contaminant Concentration < Target Value	Clean Soil	No restrictions
Contaminant Concentration > Target Value, and Contaminant Concentration < Intermediate Value	Slightly Contaminated Soil	No Further Investigation; (Minor) restrictions can be imposed on soil use
Contaminant Concentration > Intermediate Value, and Contaminant Concentration < Intervention Value	Further Investigation (After investigation still Contaminant Concentration < Intervention Value)	Restrictions can be imposed on soil use (e.g., no growth of sensitive food crops, no direct use of groundwater as drinking water)
An average soil volume concentration of at least 25 m^3 (for soil quality assessment) > Intervention Value, or An average concentration in the pore water of a water-saturated soil volume of at least 100 m^3 (for groundwater quality assessment) > Intervention Value	Seriously Contaminated Soil	Remediation will be necessary Urgency of remediation has to be determined

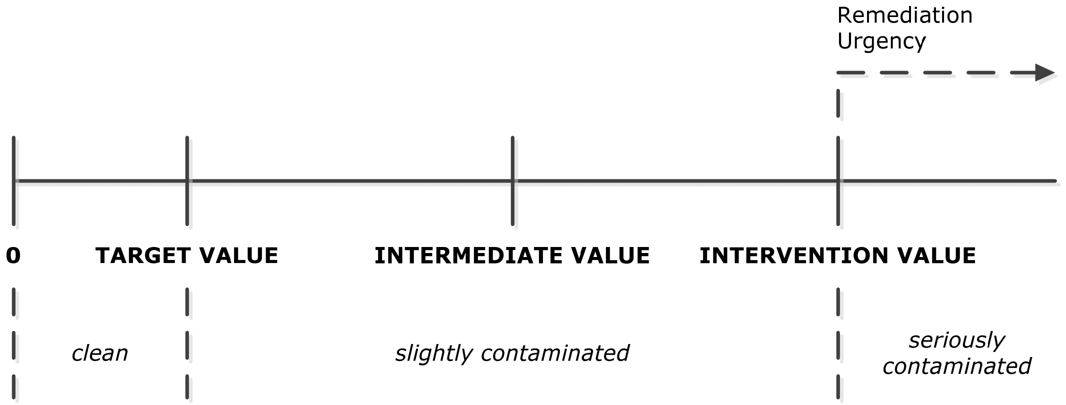


Figure 2.4. Soil and Groundwater Quality Standards and Assessment (Swartjes, 1999)

2.1.2.6 Norway

In Norway, the studies related with the management of contaminated sites were started in 1981 with "the Pollution Control Act" (Ferguson, 1999a). In 1999, the existing risk assessment methodology were improved and generic risk based soil quality criteria has been established in regard of the soil quality criteria of the Netherlands and Sweden (Ferguson, 1999a).

While developing human health risk based SQSs, seven exposure pathways are considered, namely "ingestion of soil and dust, dermal contact to soil and dust, inhalation of dust, inhalation of soil vapor, intake of drinking water (groundwater), consumption of vegetables grown at the site and consumption of fish/shellfish from a nearby seawater recipient" (SFT, 1999). For derivation of the pathway specific SQSs, the equations of the "Swedish Naturvardsverket's Model" is used with some adjustments (SFT, 1999). The soil quality criteria for each pathway are calculated based on "the most sensitive land use scenario" and harmonic mean of the pathway-specific soil quality criteria is considered as "the total human exposure concentration". In addition to the human health risk based SQSs, ecological risk based SQSs are also derived by use of the ecotoxicological data and the final SQSs are determined with respect to the lowest these values (SFT, 1999). In the end, the SQSs are adjusted with respect to "*the detection limit* for the most probable analytical method and *the Norwegian background values"* and the SQSs derived in this manner are referred as the "prevailing soil quality guidelines" (SFT, 1999). In Table 2.14, the general structure of the Norwegian SQSs look-up table is presented. The detection limit and the background values that are considered for the finalization of the prevailing soil quality guideline values can also be seen in this table. Besides, pathway specific concentrations and the total exposure for substances are presented for the most sensitive land use type to be used during risk assessment studies (see Table 2.15).

In Norway, a dilution factor of 10 is used for intake of drinking water (SFT, 1999). As mentioned before, all the calculations are performed considering the most sensitive land use scenario. Within this scenario, it is assumed that the drinking water is supplied from groundwater. Therefore, this exposure pathway may be neglected in case groundwater is not used as drinking water (SFT, 1999).

Table 2.14 The Structure of Norwegian SQSs Look-up Table

Reported background values	Previous SQGs	Health Related SQGs		Ecotox related SQGs	Ideal SQGs	Detection limit for most usual analytical method	SQGs adjusted for detection limit	Prevailing SQGs
		Sum all exposure pathways	Exclusive drinking water					

Table 2.15 Overview of the Individual Concentrations for Most Sensitive Land-Use

Ingestion of soil	Dermal contact of soil	Inhalation of dust	Inhalation of vapor	Intake of drinking water	Consumption of vegetables	Consumption of fish	Total all exposure	Total excluding intake of drinking water
mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg

2.1.2.7 Comparison of the Soil Quality Standards of Various Countries

In the previous sections, the approaches of US EPA, Canada, Germany, Netherlands, and Norway are discussed in detail. In addition to these countries, the approaches of Austria, Belgium (Flanders and Waloon), Czech Republic, Denmark, Finland, France, Italy, Lithuania, Poland, Slovak Republic, Spain, Sweden, and United Kingdom are also reviewed and all is summarized as given in Table 2.16 for easy comparison.

As seen from this table, in most of the European countries, the US and Canada, traditional concentration based soil quality criteria are replaced by risk based soil quality criteria. Although the basic principle for derivation of risk-based soil quality criteria is the same, different approaches and assumptions were adopted by different countries. For example; in some of the countries, only human health risks are considered for development of soil quality criteria (e.g., the US, France), whereas ecological risks are considered in addition to human health risks in some other countries (e.g., Austria, Belgium, Canada, Finland, Germany, the Netherlands, Norway, Spain, etc.).

Table 2.16 Comparison of SQSs of Different Countries (modified from Carlon et al., 2007)

	Land Use	**Pathways**	**Soil Criteria**	**Risk Level**	**Purpose of Use**
Austria	- agricultural and gardening purposes - non-agrarian ecosystems - residential areas, sport fields, playgrounds	- soil ingestion	Trigger Value	Intermediate Risk	Further investigation
			Intervention Values	Unacceptable Risk	In principle to be remediated (only for some contaminants)
			Site-Specific Intervention Values	Unacceptable Risk	Define the need for remediation and target concentrations
Belgium (Flanders)	- agricultural - nature - recreational - residential - industrial	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - consumption of homegrown vegetables - consumption of meat - consumption of dairy products - drinking water contaminated by permeation through pipes - showering (dermal contact and inhalation)	Background	Negligible Risk	First target for remediation
			Further Investigation	Intermediate Risk	For historical contaminants only
			Clean-up Standards	Unacceptable Risk	For new contaminants only
			Site-Specific Intervention Values	Unacceptable Risk	Only for historical pollution: need for remediation.
Belgium (Waloon)	- agricultural - nature - recreational - residential - industrial	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - consumption of homegrown vegetables - consumption of groundwater - drinking water contaminated by permeation through pipes - showering (dermal contact and inhalation)	Reference Value (Background)	Negligible Risk	Target for remediation
			Trigger values	Intermediate Risk	Further investigation
			Intervention Values	Unacceptable Risk	In principle to be remediated
			Site-Specific Intervention Values	Unacceptable Risk	Only for historical pollution: need for remediation

Table 2.16 Comparison of SQSs of Different Countries (modified from Carlon et al., 2007) (cont'd)

	Land Use	**Pathways**	**Soil Criteria**	**Risk Level**	**Purpose of Use**
Canada	- agricultural - residential/park lands - commercial - industrial	- soil ingestion - dermal contact - inhalation of dust - ingestion of groundwater - inhalation of vapors (indoor air) - consumption of homegrown products - consumption of meat - consumption of dairy	Soil Quality Guidelines	Negligible Risk	Designate clean down to levels
Czech Republic	- agricultural - nature - recreational - residential - industrial	- soil ingestion - inhalation of dust (outdoor) - dermal contact - consumption of homegrown products - consumption of meat - consumption of dairy	A	Negligible Risk	Long term objectives
			B	Intermediate Risk	Further investigation
			C	Unacceptable Risk	In principle to be remediated
Denmark	- generic	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor)	Soil Quality Criteria	Intermediate Risk	Further investigation
			Cut-off values	Unacceptable Risk	In principle to be remediated – for immobile contaminants
Finland	- residential	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - consumption of homegrown vegetables - ingestion of soil attached to homegrown vegetables - drinking water contaminated by permeation through pipes - inhalation of volatilized domestic water - showering (dermal contact and inhalation)	Threshold Values	Intermediate Risk	Site-specific assessment required
			Lower Guidelines (applied during site-specific risk assessment)	Unacceptable Risk	Risk reducing measures are required In principle to be remediated
			Upper Guidelines (applied during site-specific risk assessment for industrial or similar insensitive sites)	Unacceptable Risk	Risk reducing measures are required In principle to be remediated

Table 2.16 Comparison of SQSs of Different Countries (modified from Carlon et al., 2007) (cont'd)

	Land Use	**Pathways**	**Soil Criteria**	**Risk Level**	**Purpose of Use**
France	- sensitive use (residential) - non-sensitive use (commercial/ industrial)	- soil and dust ingestion - consumption of homegrown produce - dermal absorption from soil and dust	Source/Soil Definition Values	-	Used only in the framework of risk assessment scoring system which helps to hierarchies the contaminated sites
			Fixed Impact Values	-	
Germany	- agricultural - green land - parks/recreation - playground - residential - industrial	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - consumption of homegrown vegetables - ingestion of soil attached to homegrown vegetables - consumption of homegrown fruits - ingestion of soil attached to homegrown fruits - consumption of groundwater	Trigger Values	Intermediate Risk	Define the need for further investigation
			Action Values	Unacceptable Risk	Determine the presence of soil degradation
			Site-Specific Intervention Values	Unacceptable Risk	Define the need for remediation and target
Italy	- residential/green areas - commercial/ industrial	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - consumption of groundwater	Limit values	Unacceptable Risk	In principle to be remediated (also remediation targets)
			Site-Specific Intervention Values	Unacceptable Risk	Define residual concentration limits
Lithuania	- agricultural, recreational and residential	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - consumption of homegrown vegetables - consumption of homegrown fruits	Maximum Permissible Concentrations	Unacceptable Risk	In principle to be remediated

Table 2.16 Comparison of SQSs of Different Countries (modified from Carlon et al., 2007) (cont'd)

	Land Use	Pathways	Soil Criteria	Risk Level	Purpose of Use
Netherlands	- generic	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - inhalation of groundwater vapors - consumption of homegrown vegetables - ingestion of soil attached to homegrown vegetables - consumption of groundwater - inhalation of volatilized domestic water - showering (dermal contact and inhalation)	Target Value	Negligible Risk	Long term objectives
			Intervention Value	Unacceptable Risk	Define need for site-specific assessment
			Site-Specific Risk Assessment	Unacceptable Risk	Define urgency of remediation. Remedial concentration targets for immobile contaminants
Norway	- generic	- soil ingestion - dermal contact - inhalation of dust (outdoor) - inhalation of vapors (indoor) - consumption of drinking water - consumption of vegetables - consumption of fish	Soil Quality Guidelines	Intermediate Risk	Further investigation
Poland	- agricultural and urbanized land - nature and groundwater protection - industrial, mining and transportation	-	Maximum Permissible Concentrations	Unacceptable Risk	In principle to be remediated
Slovak Republic	- agricultural - generic	-	A	Negligible Risk	Target for Remediation in groundwater sensitive area
			B	Intermediate Risk	Target for remediation in groundwater less sensitive areas
			C	Unacceptable Risk	Intervention values (in principle to be remediated)

Table 2.16 Comparison of SQSs of Different Countries (modified from Carlon et al., 2007) (cont'd)

	Land Use	Pathways	Soil Criteria	Risk Level	Purpose of Use
Spain	- natural - urban/residential - industrial	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor)	Guidance Values	Intermediate Risk	Further investigation, or site specific assessment
			Site-Specific Intervention Values	Unacceptable Risk	Define the need for remediation and target values
Sweden	- sensitive land uses - less sensitive with or without groundwater protection	- soil ingestion - dust ingestion - dermal exposure - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - consumption of homegrown vegetables - consumption of homegrown fruits - consumption of groundwater - consumption of fish and shell-fish	Trigger values	Intermediate Risk	Further investigation
United Kingdom	- allotments - natural - residential with plant uptake - residential without plant uptake - commercial/ industrial	- soil ingestion - dust ingestion - dermal exposure - inhalation of vapors (outdoor) - inhalation of dust (outdoor) - dermal exposure to dust (indoor) - inhalation of vapors (indoor) - consumption of homegrown vegetables - ingestion of soil attached to homegrown vegetables	Soil Screening Values (SSVs) for ecological receptors	Intermediate Risk	Triggers further investigation
			Refinements made to measured field concentrations and then compared with SSVs for ecological receptors	Intermediate Risk	Triggers for further investigation
			Soil Guideline Values	Unacceptable Risk	Site specific assessment required
			Site-Specific Intervention Values	Unacceptable Risk	Define the need and target for remediation
US EPA	- residential - commercial/ industrial: outdoor worker - commercial/ industrial: indoor worker	- ingestion - dermal absorption - inhalation of fugitive dusts (outdoor) - inhalation of vapors (outdoor) - migration to groundwater	Soil Screening Levels	Intermediate Risk	Define the need for action, or further investigation

Some countries (e.g., Denmark, Netherlands, Norway, Slovak Republic) use single *generic* soil quality criteria (not land use or pathway specific), while some of the countries, such as Austria, Belgium, Canada, Czech Republic, etc. use soil quality criteria that are defined on the basis of different land use types, or of the sensitivity of the site (e.g., France, Sweden). Different from these approaches the US provide soil criteria based on the generic human exposure pathways.

Although the principle underlying the development of human health risk based soil quality criteria is common for all countries, different assumptions and different parameter values used for calculations result in 10 to 100 folds of differences in the SQSs of different countries for the same contaminant. One of the most important parameter that affects the soil quality criteria profoundly is the *acceptable risk* determined for non-threshold compounds, which varies from 10^{-4} to 10^{-6}. In most of the countries, acceptable risk is determined as 10^{-5} (e.g., Belgium, Denmark, Finland, Germany, Norway, Sweden) whereas the Netherlands accepts 10^{-4} and the US, Canada and Italy (adopting 10^{-5} in the new regulation) accept 10^{-6} (Carlon et al., 2007).

Together with the discussions mentioned above, the reasons of differences in soil quality criteria from country to country can be summarized as follows (Carlon et al., 2007):

- Geographical and biological (environmental variability),
- Socio-cultural (variability in social behaviors and land use),
- Regulatory (variability in regulatory requirements, such as constitutional aspects or commonalities with other existing laws),
- Political (variability in the prioritization of environmental and economic values),
- Scientific (variability in the arguments of different scientific views)
  - consideration of different exposure scenarios (different land use types and exposure pathways),
  - use of different values for variables (exposure duration and frequency, body weight, soil ingestion amount, inhalation rate, dilution factor etc.),
  - use of different toxicological data, and
  - consideration of different risk levels (10^{-4} to 10^{-6}).

As much as the approach and the assumptions adopted for development of the soil quality criteria, the purpose of use of these standards (in other words, the role of soil quality criteria) is important. For instance; two levels of criteria is proposed by the Netherlands. One of them (target value) is considered as the long term objectives. The site concentrations below this value pose *negligible risk* and require no further action. However, the higher criteria (intervention value) designate *unacceptable risk* and the site concentrations exceeding the intervention value require further investigation (Carlon et al., 2007). In this respect, the use of SQSs also varies from country to country. Carlon et al. (2007) classifies soil quality criteria based on their role in contaminated sites management system as follows (also given in Figure 2.5):

- negligible risk,
- intermediate (warning) risk, and
- potentially unacceptable risk.

The soil criteria that are considered as long term target values are classified within *negligible risk values* and they are mostly not related to the land use type (Carlon et al., 2007). In most of the countries, the soil quality criteria, which designate *intermediate risk*, require further investigation in case it is exceeded. On the other hand, soil quality criteria that take place within *potentially unacceptable risk* indicate the need for remediation.

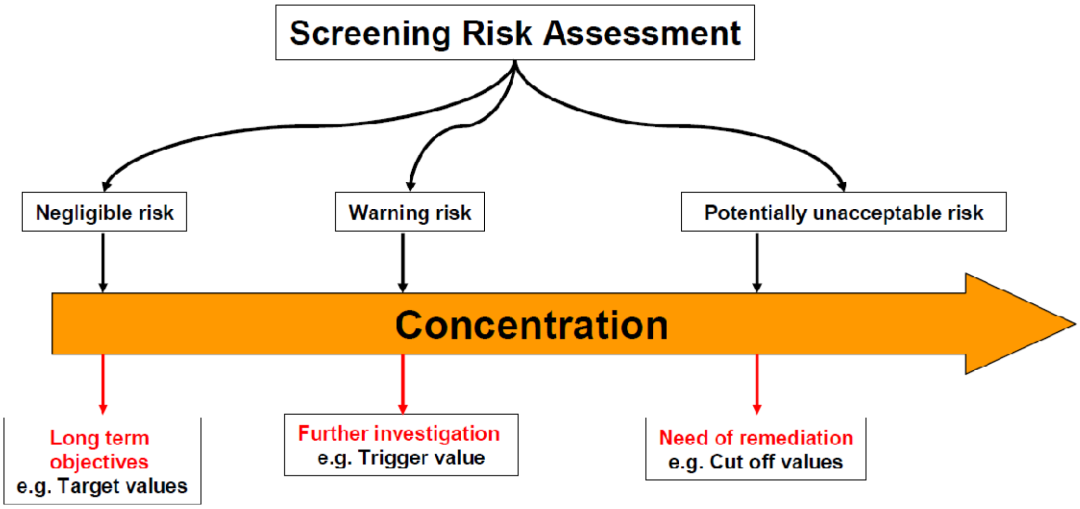


Figure 2.5 SQSs Based on Various Risk Levels (Carlon et al., 2007)

2.2 METHODOLOGY FOR DEVELOPMENT OF TURKISH SOIL QUALITY STANDARDS

The schematical illustration of the methodology used for development of human health risk based SQSs for Turkey is shown in Figure 2.6. Within the context of the conceptual framework (1st phase), first of all, a general overview of the approaches for development of risk based SQSs had to be drawn and the needs of Turkish regulation in terms of SQSs had to be identified. For this purpose, the approaches of the North American countries and the EU countries were reviewed (described in Section 2.1.2). With the insight gained from these countries' approaches, the other components to accomplish the study objectives were determined.

In this respect, the steps to be followed are determined as: (i) identification of the needs of Turkish SPCR (MoEF, 2005a) in terms of SQSs and the role of the SQSs within the recently developed contaminated sites management system (MoEF, 2010) (Section 2.2.1), (ii) identification of the potentially soil contaminating activities for Turkey and the potential soil contaminants arising from these activities (Section 2.2.2), (iii) determination of the most appropriate approach to be utilized for development of human health risk based SQSs for Turkey and identification of the key elements for such a study (Section 2.2.3). Within the last task, the acceptable (target) risk level (Section 2.2.3.1), generic exposure scenario (land use scenario), relevant exposure pathways and sensitive receptors (Section 2.2.3.2), generic values for the exposure parameters and contact rates (Section 2.2.3.3), generic soil characteristics (Section 2.2.3.4), and data requirement for physical-chemical data (Section 2.2.3.5) and for toxicological data (Section 2.2.3.6) were needed to be determined. The detailed description for each of these components is given in the sections specified. Finally, in Section 2.2.4, all of these components are integrated within under the equations used for derivation of human health risk based SQSs. The contaminants that need special attention during derivation of risk based SQSs are also mentioned in Section 2.2.5.

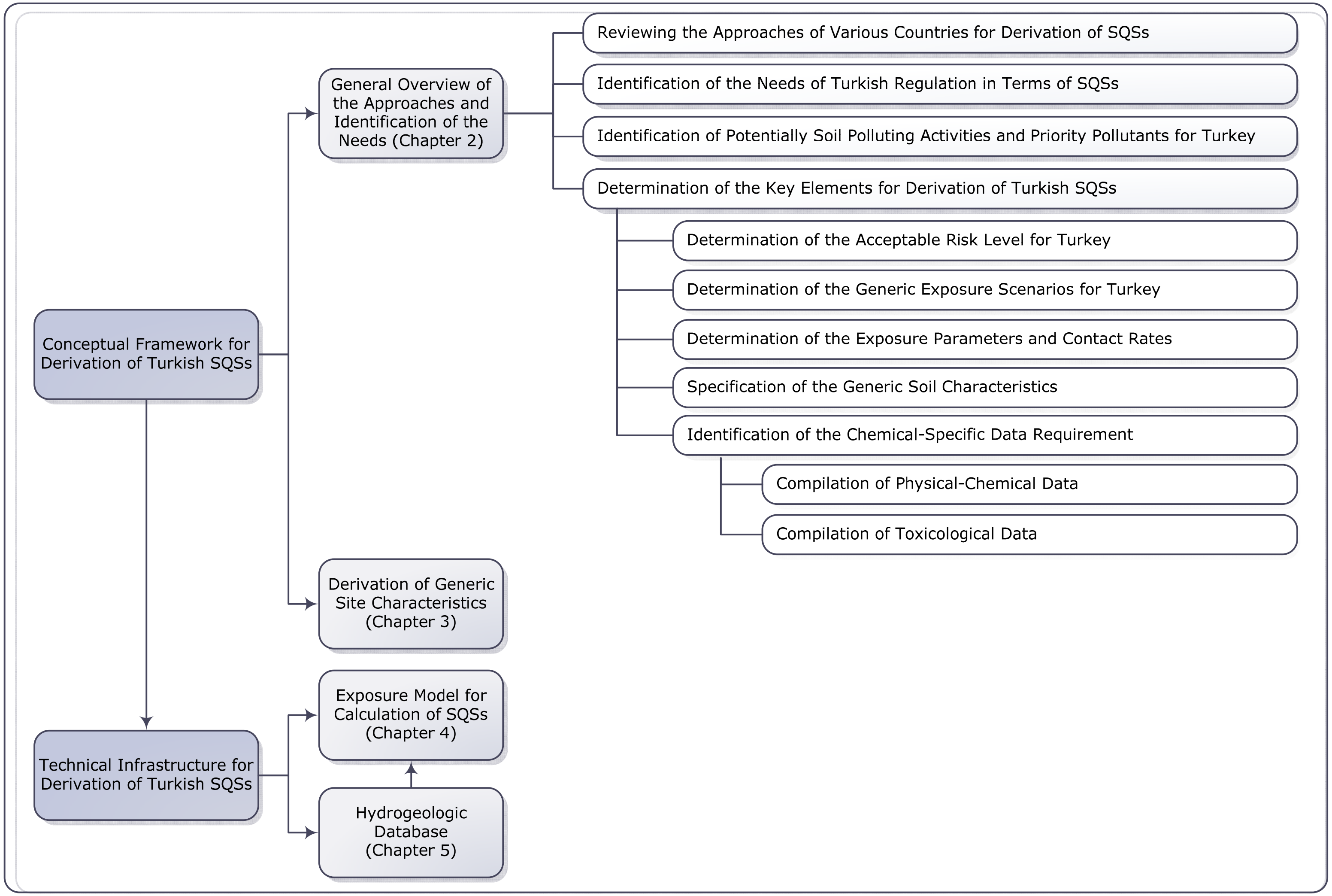


Figure 2.6 Conceptual Framework for Derivation of Turkish Human Health Risk Based SQSs

2.2.1 The Needs of Turkish Regulation in Terms of Soil Quality Standards

The history of Turkish regulations on soil pollution control is described in Section 2.1.2.1. Since the soil quality standards (SQSs) given in the regulation were focusing mainly on the use of stabilized sludge on soil, it was far away from providing common criteria for evaluation of the soil quality. Because of these reasons, the regulation could not been implemented by the Ministry of Environment and Forestry (MoEF) effectively. The environmental pollution problems encountered in Turkey during the recent years resulting from industrial accidents, chemical spills and leakages from storage tanks, illegal waste dumping, and spills from petroleum transfer lines are concrete examples strengthened the need for a comprehensive soil regulation and effective tools, such as generic SQSs which defines the state-of-art for management of contaminated sites.

In order to fulfill the needs of Turkish MoEF, a contaminated sites management system was established within the context of a TUBITAK Project (described in Section 2.1.2.1). The management system was also included in the new regulation titled “Regulation on Soil Pollution Control and Sites Contaminated with Point Sources” (MoEF, 2010). During the development of the contaminated sites management system, the position and function of the SQSs in the system were identified (Ünlü et al., 2009). According to the management system, the new SQSs were expected:

- to be protective of human health concerning a conservative generic scenario and its relevant exposure pathways,
- to aid in screening the sites that do not need further attention and identifying the sites that need further (site-specific) investigation,
- to be in line with the latest scientific developments, findings and experiences allowing proper allocation of available resources,
- to meet current needs of the soil regulation and to confront the future needs,
- to be as simple as possible, easy to understand, implement and sustain by the stakeholders (the regulatory agencies, such as provincial organizations of the MoEF, the representatives of the industrial sectors, consultancy firms, public etc.) of the regulation and flexible to accommodate future developments.

In this respect, development of human health risk based SQSs were considered as the best approach for investigation of potentially contaminated soils.

2.2.2 Potentially Soil Polluting Activities and Priority Pollutants for Turkey

Ferguson (1999a) emphasizes that soil contamination events are mostly associated with industrial activities. According to EEA, “about 41% of the soil contamination is resulting from industrial and commercial services and the number of contaminated sites in Europe has grown approximately up to 250,000 sites” (URL 1). In this respect, it is essential to identify the potentially soil contaminating activities, the potential soil contaminants arising from these activities and the list of priority contaminants for which SQSs should be derived and included in the regulation.

In Turkey, various kinds of industrial sectors are in operation. The foremost common industries of Turkey are listed in the Sector Profiles of Turkish Industry Report prepared by State Planning Organization (2004) as follows:

- Mining activities
- Food industry
- Beverages industry
- Tobacco products industry
- Textile and clothing industry
- Leather and leather goods industry
- Wood and cork products
- Paper and paper products
- Printing and publishing
- Coke and petroleum products industry
- Chemical industry
- Pharmaceutical industry
- Fertilizer industry
- Petrochemical industry
- Glass industry
- Cement industry
- Ceramic industry
- Refractory materials industry
- Iron and steel industry
- Nonferrous metals industry
- Machinery industry
- Automotive industry
- Information and communication technologies industry

Many industrial activities are considered to be the main cause of soil contamination and thus viewed as potential contaminated site. In regulatory sense, contaminated site is defined as “*a site where there is a confirmed presence, of anthropogenic* ***dangerous substances*** *of such a level that they pose a significant risk to human health or the environment*” (EU COM, 2006a).

Therefore, for identification of potential contaminating activities and the contaminants associated with those industries that have potential to contaminate soil, it is important to reveal the industries that include/generate hazardous substances in their processes.

With this concern, the activities in Turkey generating hazardous wastes were assessed as the potential contaminated sites. Although the MoEF and State Institute of Statistics are regarded as the sources for this type of information, these statistics do not provide sufficient information on the inventory for industrial wastes (Yılmaz, 2006). Therefore, a study performed by Yılmaz (2006), which is based on a detailed evaluation of hazardous waste generating activities in Turkey, is used for identification of the industries generating hazardous wastes. The following activities are considered as important sources of hazardous wastes in Turkey (Yılmaz, 2006):

- mining activities (exploration, mining, quarrying and physical and chemical treatment of minerals),
- wood processing,
- petroleum refining, natural gas purification and pyrolytic treatment of coal,
- inorganic chemical processes,
- organic chemical processes,
- thermal processes,
- chemical surface treatment and coating of metals and other materials, non-ferrous hydrometallurgy,
- oil wastes and wastes of liquid fuels,
- organic solvents, refrigerants and propellants,
- electrical and electronic equipment,
- batteries and accumulators,
- wastes from human or animal health care and/or related research,
- wastes from incineration or pyrolysis of waste, and
- municipal wastes.

Among these sectors, organic chemical industry is estimated to have the highest portion in hazardous waste generation (around 480,000 tons/yr) (Yılmaz et al., 2009). The sub-groups of this sector that generate considerable amounts of hazardous wastes are listed as "pharmaceutical industry (30%), organic plant production and biocides (26%), plastic manufacture (21%), organic dye and pigment (20%) and fats, grease, soaps manufacture (3%)" (Yılmaz et al., 2009).

Although the Regulation on Soil Pollution Control and Sites Contaminated by Point Sources (MoEF, 2010) stipulates the registration of the contaminated sites in the country, a complete inventory of contaminated sites does not exist, yet. Because of this reason, information on the common pollutants observed at the contaminated sites in Turkey could not be obtained. However, keeping the abovementioned industrial sectors in mind, the potentially soil polluting activities and the most frequently observed soil contaminants in the European Countries were assessed.

The primary sources of soil contamination in Europe are presented by European Environment Agency (EEA) (URL 1) as given in Figure 2.7 with respect to % of the number of sites where preliminary investigations have been completed. According to this figure, industrial production and commercial service, municipal waste treatment and disposal, industrial waste treatment and disposal are shown among the foremost activities causing soil contamination.

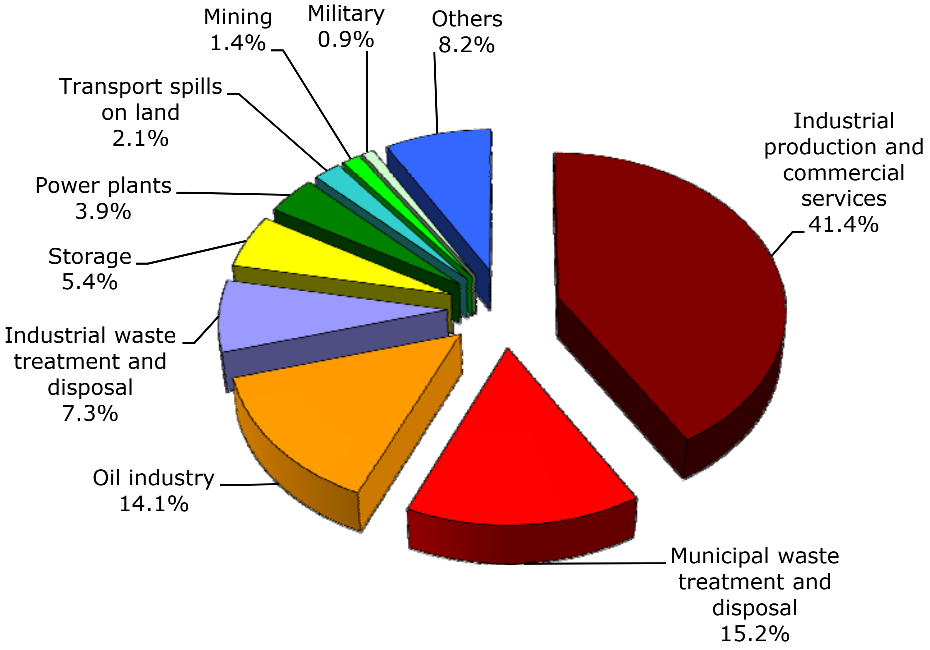


Figure 2.7 Primary Sources of Soil Contamination in Europe (URL 1)

Handling losses, leakages from tanks and pipelines, and accidental spills of chemicals at industrial and commercial sites are reported to be the main sources of soil pollution in Europe (URL 1). Especially, the chemical and metal working industries, energy production and the oil industry are considered among important sources of soil pollution, while the gasoline stations and dry cleaners are regarded as the sources that pose significant environmental and human health effects in some of the European countries (URL 1).

In fact, Figure 2.7 and the profile of common industrial activities in Turkey show that the potentially soil contaminating activities in Turkey are comparable with the ones experienced in the European countries. Although the main sources of soil pollution and the main contaminants vary from country to country, heavy metals and mineral oil are found to be the most frequent soil contaminants in Europe (URL 1). On the other hand, mineral oil and chlorinated hydrocarbons are found to be the most frequent contaminants in groundwater. Polycyclic aromatic hydrocarbons (PAH), aromatic hydrocarbons (BTEX), phenols, chlorinated hydrocarbons (CHC), the other inorganic compounds, and asbestos are named as the other significant contaminants for soil (URL 1) (see Figure 2.8).

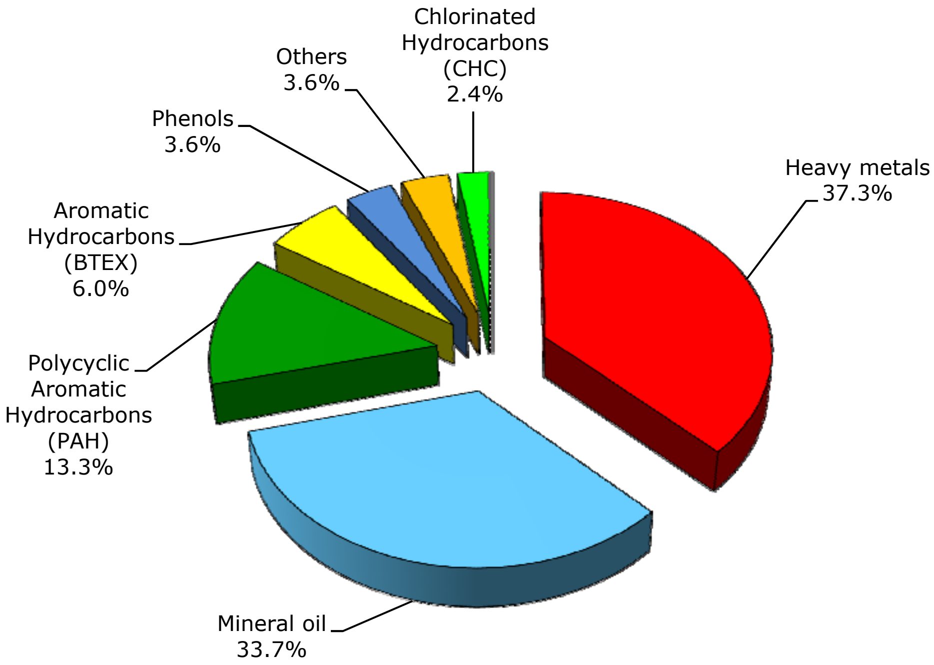


Figure 2.8 Primary Soil Contaminants in Europe (URL 1)

In the light of the information presented above, it was decided to develop a table which includes the potential sources of soil contamination and the priority soil contaminants arising from these sources. For this purpose, the following references were studied to identify the potential soil pollutants associated with the potentially soil polluting activities in Turkey:

- *the list of indicator contaminants given in the Regulation on Soil Pollution* Control and Sites Contaminated by Point Sources (Ünlü et al., 2009; MoEF, 2010),
- *Industry Profile Reports* produced by UK Environment Agency (EA) (URL 4), Department of the Environment (reports including information on the processes, materials and wastes associated with various industries),
- The work of Demetriades (2007) which lists soil contaminants associated with each soil polluting industry.

By using these documents, Table B.1 given in Appendix-B was produced. In this table, the potentially soil contaminating activities important for Turkey are listed with respect to their NACE Codes and potential soil pollutants (or groups of pollutants) for each activity are indicated. This table is then utilized to identify the priority contaminants for Turkey.

Furthermore, the chemical substances listed in the regulations of other countries (i.e., Germany, France, Norway, Canada, Spain, Netherlands, and US EPA) were reviewed, since the chemicals given in the regulations represent the most commonly observed soil contaminants in a country. For example, the US EPA’s list represents the commonly found contaminants at sites on the National Priorities List (NPL), which designates the sites having priority among the known contaminated sites throughout the US and its territories (US EPA, 1996b).

The main groups of contaminants listed in the regulations of these countries include aromatic hydrocarbons, polycyclic aromatic hydrocarbons, halogenated aliphatic hydrocarbons, halogenated aromatic hydrocarbons, halogenated polycyclic hydrocarbons, pesticides, ketons, phenols and chlorophenols, phthalates, organic nitrogen compounds, metals, and other inorganic chemicals. The contaminants covered by these regulations are presented in Table B.2 of Appendix-B.

The priority soil contaminants for Turkey are identified by use of Table B.2, as well as the compounds given in "the priority hazardous contaminants list" of Corbitt (1990). The twelve compounds being in subject of Stockholm Agreement on "Persistent Organic Polluters (POPs)", which has been signed by Turkish MoEF, were also considered for preparation of the priority contaminants list for Turkey. Among these compounds; DDT, heptachlor, chlordane, aldrine, dieldrine, endrine, toxaphene, PCB, hexaclorobenzen, dioxins and furans are already covered by other countries. The only compound, *mirex*, that has not been covered by other countries' regulations were also included in the list of priority contaminants. Since SQSs are calculated by using chemical-specific toxicological data, the presence of toxicity data for each chemical in Table B.2 was also assessed. The chemicals, for which no toxicological data is available, removed from the priority pollutants list. For example; some of these countries developed their soil criteria based on the groups of compounds instead of individual compounds, such as BTEX (benzene, toluene, ethylbenzene and xylene), PAHs (polyaromatic hydrocarbons), PCBs (polychlorinated biphenyls), HCHs (hexachlorocyclo-hexans), chlorobenzenes, organotin compounds, dioxins and furans. However, for some of these compounds, no toxicological data were found in literature (e.g., BTEX, PAHs, HCHs, etc.). Therefore, some of these total compounds were not included in the priority list or special procedures were applied (discussed in Section 2.2.5). As a result of the discussions made above, the priority soil contaminants are identified as given in Table 2.17.

2.2.3 Key Elements for Derivation of Turkish SQSs

In regard to the needs of Turkish regulation in terms of SQSs (described in Section 2.2.1), the approach for derivation of Turkish SQSs were determined. For this purpose, the experiences and scientific findings of the other countries (described in Section 2.1.2) was utilized. In this section, the approach adopted for derivation of Turkish SQSs and the key elements of this approach are described.

Table 2.17 Priority Soil Contaminants for Turkey

ORGANICS

Acenaphthene
Acetone (2-Propanone)
Acrolein
Acrylamide
Acrylonitrile
Aldrin
Anthracene
Atrazine
Benz(a)anthracene
Benzene
Benzidine
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzoic acid
Bis(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-ethylhexyl)phthalate
Bis(chloromethyl)ether
Bromodichloromethane
Bromoform
Butanol
Butyl benzyl phthalate
Carbaryl
Carbazole
Carbofuran
Carbon disulfide
Carbon tetrachloride
Chlordane
p-Chloroaniline
Chlorobenzene
Chlorodibromomethane
Chloroform
Chloromethane
beta-Chloronaphthalene
2-Chlorophenol
Chrysene
m-Cresol
o-Cresol
p-Cresol
Cyclohexanone
DDD
DDE
DDT
Dibenz(a,h)anthracene
1,2-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
1,2-cis-Dichloroethylene
1,2-trans-Dichloroethylene
2,4-Dichlorophenol
2,4-Dichlorophenoxy acetic acid
1,2-Dichloropropane
1,3-Dichloropropene
Dieldrin
Diethylphthalate
2,4-Dimethylphenol
Dimethylphthalate
Di-n-butyl phthalate
4,6-Dinitro-o-cresol
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-n-octyl phthalate
1,2-Diphenylhydrazine
Endosulfan
Endrin
Ethylbenzene
Fluoranthene
Fluorene
Furan
Heptachlor
Heptachlor Epoxide
Hexachloro-1,3-butadiene
Hexachlorobenzene
α-HCH (α-BHC)
β-HCH (β-BHC)
γ-HCH (Lindane)
Hexachlorocyclopentadiene
Hexachloroethane
Hydroquinone
Indeno(1,2,3-cd)pyrene
Isophorone
Maneb
MCPA
Methoxychlor
Methyl bromide
Methyl Tert-Butyl Ether (MTBE)
Methylene chloride
Naphthalene
Nitrobenzene
2-Nitrophenol
4-Nitrophenol
N-Nitrosodimethylamine
N-Nitroso-di-N-propylamine
N-Nitrosodiphenylamine
PCBs (low risk and persistence)
PCBs (high risk and persistence)
Pentachlorobenzene
Pentachlorophenol
Phenol
Pyrene
Pyridine
Styrene
1,2,4,5-Tetrachlorobenzene
2,3,7,8-TCDD
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Tetraethyllead
Toluene
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16) *
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35) *
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8) *
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16) *
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35) *
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9) *
Toxaphene
Tributyltin oxide
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol
Vinyl acetate
Vinyl chloride (chloroethene)
Xylene, mixture
m-Xylene
o-Xylene
p-Xylene

Table 2.17 Priority Soil Contaminants for Turkey (cont'd)

INORGANICS		
Antimony	Cobalt	Thallium
Arsenic	Copper	Tin
Barium	Lead	Titanium
Beryllium	Mercury	Vanadium
Cadmium	Molybdenum	Zinc
Chromium (III)	Nickel	Cyanide
Chromium (total)	Selenium	Thiocyanate
Chromium (VI)	Silver	

* EC: equivalent carbon number.

As explained in Section 2.1.2, in most of the European countries, Canada and the US, human health risk based soil criteria are being in use. On the other hand, some of these countries (e.g., Canada, the Netherlands, Spain, etc.) have already developed their soil criteria also to protect ecological receptors and some of the countries are currently working to develop ecological soil criteria. Being a relatively new field of interest compared to human health risk assessment, environmental risk assessment requires a broad knowledge on exposure assessment and dose-respond assessment performed on ecological receptors. Hence, development of ecological soil criteria is another area of concern requiring country specific data on potential ecological receptors, which is not available for Turkey yet. Therefore, development of human health risk based SQSs was determined to have the priority for Turkey.

As mentioned in Section 2.1.2.7, although the same principles are utilized for derivation of human health risk based SQSs, the countries end up with different soil criteria and, as mentioned, one of the reasons for this situation is due to the differences in intended use of (the role of) the SQSs, such they pose different levels of risk (i.e., negligible, intermediate, and unacceptable risk). Because of this reason, the role of the SQSs within the contaminated sites management system has to be clarified in the beginning of the studies for development SQSs. In the framework of the recently developed contaminated sites management system for Turkey that take place within the new regulation (Ünlü et al., 2009; MoEF, 2010), the role of the SQSs was defined as the generic standards used to eliminate sites that do not need further attention and to identify sites that require further site-specific risk assessment (SQSs correspond to intermediate risk level).

Although the general approaches of the countries (mentioned in Section 2.1.2.7) could be obtained, only a few of these countries' calculation procedures for derivation of SQSs were available in the literature. Nevertheless, the available documents, reports, regulatory standards and guidelines of the countries (i.e., the US EPA, Canada, Germany, the Netherlands, and Norway) having well developed human health risk assessment system were collected and compared with each other. In fact, the algorithms used for derivation of human health risk based SQSs are similar, the differences in the approaches (discussed in Section 2.1.2.7) result in derivation of different numerical values for SQSs. Therefore, it was decided to follow US EPA's general approach for development of Turkish SQSs due to its comprehensive documentation and availability of reports in English, as well as its development based on long term practice and experiences gained in this area.

Besides, it should be noted that, the approaches of the other countries were also utilized for derivation of Turkish SQSs. For example; US EPA's, Canadian and Norwegian approaches were compared for determination of a generic dilution factor (described in Section 2.2.4.3) to calculate generic SQSs for migration to groundwater pathway. The Norwegian approach was adopted for comparison of SQSs developed with the background soil concentrations and detection limit of a chemical of concern and adjusting the SQSs with respect to those values (described in Section 2.3.2). For derivation of the air dispersion factor (used to calculate SQSs for inhalation of volatiles and dusts) for Turkey, the approaches of both the US EPA and the UK Environmental Agency (EA) were examined and appropriate values were determined by comparison (described in Chapter 3). The exposure models (or software) commonly used in the European Countries and in the US were utilized for development of the computational tool to be used for calculating Turkish generic and site-specific human health risk based SQSs (described in Chapter 4).

With regard to US EPA's approach, the generic SQSs for Turkey was decided to be developed based on the "reasonable maximum exposure (RME)" of human receptors in a residential setting (US EPA, 1989). In RME assumption, "reasonably conservative values for intake and duration" are considered (US EPA, 1989; US EPA, 1991). Thus, all site-specific parameters in calculations are determined with respect to the average or typical site conditions for soil characteristics and meteorological conditions (US EPA, 1996c). In this respect, it was decided to derive generic SQSs for Turkey by revising the site-specific parameters according to the typical or average characteristics of Turkey.

The following sub-sections are organized to explain the key elements for derivation of SQSs which include the studies performed for determination of a target (acceptable) risk level (Section 2.2.3.1), the generic exposure scenarios and pathways considered (Section 2.2.3.2), the generic values used for exposure parameters and contact rates (Section 2.2.3.3), derivation of generic site characteristics for Turkey (Section 2.2.3.4) and compilation of physical-chemical (Section 2.2.3.5) and toxicological data (Section 2.2.3.6) for derivation of Turkish SQSs.

2.2.3.1 Target (Acceptable) Risk Level

As mentioned in Sections 2.1.1.5 and 2.1.2.7, the *target risk level (TRL)* determined for non-threshold compounds by different countries/organizations varies from 10^{-4} to 10^{-6}. Considering the risk levels accepted by different organizations/ countries (e.g., WHO, EU, US EPA, etc.), the TRL for Turkey was discussed with the staff of Soil and Water Department of the MoEF (Ünlü et al., 2009). With the opinion of the MoEF, it was decided to set a conservative TRL for Turkey and derive the generic SQSs with respect to this level. Finally, the target risk level was determined as 10^{-6}, meaning one-in-a-million excess lifetime cancer incidence.

The TRL of 10^{-6} could be considered to be more strict compared to most of the European countries. However, it is completely related to the purpose of use (the role) of the soil criteria within the contaminated sites management system. Turkish SQSs developed are intended to be used for screening the sites that do not need further attention, or for highlighting the sites that need further site investigation and assessment. Therefore, the site concentrations below generic SQSs could be screened from further investigation without any doubt.

A TRL of 10^{-6} is considered to be appropriate for Turkey, at the beginning of implementing the risk-based contaminated site management system. However, TRL may be re-evaluated in the future, with respect to the requirements of the regulation, or to the experience gained in this field.

On the other hand, as can be remind from Section 2.1.1.4, for evaluation of the non-carcinogenic effects of contaminants, hazard quotient, which is the ratio of exposure level of contaminant to reference dose (*RfD*), is used and safe exposure levels (SQSs) are derived based on a hazard quotient of ‘1’.

2.2.3.2 Generic Exposure Scenarios and Pathways

For derivation of generic SQSs for Turkey, the residential land use scenario, for which human receptors are more susceptible to exposure to soil contaminants, was considered to be a conservative scenario. Residential land use assumption was also reasonable for protection of the sensitive receptors (i.e., children and adults). However, the generic SQSs developed based on the residential land use assumption would be too conservative for some industrial sites where residential settings are not in the area of influence. Because of this reason, the US EPA approach was taken as the basis and commercial/industrial land use scenario was also considered for derivation of Turkish SQSs. For industrial/commercial land use, two types of receptors are of concern; outdoor workers and indoor workers (US EPA, 2002a). Since different exposure pathways and exposure parameters apply for these receptors, the generic SQSs derived for commercial/industrial land use: outdoor worker and commercial/industrial land use: indoor worker are different.

As discussed in Section 2.1.2.7, some of the countries established their soil criteria based on land use types (e.g., Canada, Germany, Austria, Belgium, etc.), whereas the US EPA present pathway-specific soil criteria for the concerned exposure scenarios (i.e., residential, commercial/industrial). For development of Turkish generic SQSs, pathway specific soil criteria were regarded as a more appropriate approach because of its comparative use during sampling practices. In order to measure contaminant levels in soil, two kinds of soil sampling strategy are performed; surface soil sampling (addresses ingestion, dermal and inhalation of fugitive dust pathways) and subsurface soil sampling (addresses inhalation of volatiles and migration to groundwater pathways) (US EPA, 1996a). In this regard, pathway specific soil criteria are advantageous allowing the comparison of surface and subsurface soil concentrations with the allowable soil concentrations for each pathway of concern. Furthermore, pathway specific SQSs allow, for particular cases, to disregard the soil criteria given for that pathway and to exclude the pathway that is not of concern from further investigation.

In this respect, the main exposure pathways of the US EPA listed below were taken into consideration for derivation of human health risk based SQSs;

- combined ingestion-dermal contact pathway,
- outdoor inhalation of fugitive particulates,
- outdoor inhalation of volatiles,
- ingestion of groundwater (migration to groundwater).

The abovementioned exposure pathways are also considered in most of the countries, such as Germany, Norway, Canada, the UK, etc. However, in Belgium (Flanders and Waloon), Finland and the Netherlands ingestion of contaminated groundwater is not a generic pathway of concern, due to infrequent use of groundwater as potable water. Instead, *drinking water contaminated by permeation through pipes* is considered. Whereas, ingestion of contaminated groundwater is an important pathway for Turkey, because of the frequent use of groundwater supplies in the country.

As a consequence, three different land use scenarios were considered for development of generic human health risk based SQSs for Turkey. Exposure pathways and receptors of concern for each of these land use scenarios are summarized below:

- *Residential Scenario:* In this scenario, children and adults are considered as the potential receptors. Ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive particulates and migration to groundwater are considered as the main exposure pathways.
- *Commercial/Industrial Scenario - Outdoor Worker:* In this scenario, adults are considered as the potential receptors. Ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive particulates and migration to groundwater are considered as the main exposure pathways.
- *Commercial/Industrial Scenario - Indoor Worker:* In this scenario, adults are considered as the potential receptors. Ingestion and migration to groundwater are considered as the main exposure pathways.

No other land use scenarios were considered within generic risk assessment. Because, derivation of generic soil criteria for other land use scenarios, such as agricultural land use scenario and construction exposure scenario includes several variables for exposure conditions. For instance, in agricultural land use scenario, human uptake from raised and consumed farm products and human exposure to contaminants through consumption of beef, milk and vegetables have to be considered (Kerr et al., 1998). In order to do that, farming practices across the country have to be known to identify various parameters to be used for calculating chemical concentrations in farm products (Kerr et al., 1998). In addition, the toxicological information to be used for calculation of plant uptake is lacking for Turkey. Similarly, for some of the exposure pathways, it is hard to identify generic site characteristics for Turkey. For example, *inhalation of volatiles in indoor air pathway* requires inputs such as dimensions of commercial buildings, the distance between contamination and a building's foundation, floor crack area, etc. (US EPA, 2002a), for which it is difficult to define typical conditions for Turkey. Likewise, for pathways, such as *consumption of homegrown products* or *consumption of meat, dairy or fish*, it is very difficult to make generalization for the whole country and to specify standardized values for parameters, because at every region of Turkey, people has different living standards and different consumption habits depending on the environment they live.

On the other hand, with respect to the contaminated sites management system that takes place in the new Regulation on Soil Pollution Control and Sites Contaminated with Point Sources (MoEF, 2010), generic SQSs are aimed to be used during generic risk assessment phase. In case additional human exposure pathways are identified, then site-specific risk assessment would be performed for that site. Thus, specified exposure scenarios and pathways are considered to be protective for the sites that do not include additional pathways.

2.2.3.3 Exposure Parameters and Contact Rates

Exposure to contaminants by humans is termed as “intake” (or “uptake”) and expressed in terms of “the intake of mass of substance per unit body weight per unit time (mg/kg-day)” (US EPA, 1989). In order to estimate chemical intakes, human exposure to chemicals is considered. The exposure parameters and contact rates used in derivation of SQSs are listed in Table 2.18 together with the explanations for their purpose of uses.

US EPA determined the values for the exposure parameters and contact rates with respect to the ***reasonable maximum exposure*** (RME) assumption, which is based on “the highest exposure that is reasonably expected to occur at a site”

(US EPA, 1989; US EPA, 1996a). Thus, the generic values for these variables represent the conservative situation in regard of the characteristics of the potentially exposed population (US EPA, 1989).

Table 2.18 Exposure Parameters and Contact Rates Required for Derivation of SQSs (US EPA, 1989; UK EA, 2009)

Parameters	**Significance**
EF (exposure frequency)	Represents the number of days per year in which a daily exposure event is considered to occur.
ED (exposure duration)	Refers to the length of time in years that a critical receptor assumed to be exposed to contaminant. Exposure frequency and exposure duration are used to estimate the total time of exposure.
EV (event frequency)	Refers to the number of events expected to occur per day.
IR (ingestion rate of soil)	Provides information on the amount of soil ingested on a daily basis.
$\boldsymbol{IR_w}$ (ingestion rate of groundwater)	Provides information on the amount of groundwater ingested on a daily basis.
SA (skin surface area exposed)	Refers to the surface area of the skin that is open for dermal contact.
AF (skin-soil adherence factor)	Provides information on the amount of soil adhered to, or in intimate contact with the skin, over the contact period for a single event.
BW (body weight)	Refers to average body weight over the exposure period. For exposures occurring during childhood years, average child body weight is used. For exposures occurring throughout the lifetime, age adjusted exposures are calculated.

US EPA (1989) recommends the use of reasonable conservative estimates for the contact rates, when necessary statistical data are not available. Since there exist no statistical record for Turkey related to the contact rates of individuals to soil contaminants, the generic values of US EPA for ingestion rate, exposure duration and exposure frequency were decided to be used for derivation of Turkish SQSs. Since the values for the exposure parameters (i.e., body weight, skin surface area exposed, and skin soil adherence factor) are also based on scientific basis and representing conservative situations, the values for these parameters were also considered to be applicable for Turkey. Thus, the generic values for the exposure parameters and contact rates used for calculating Turkish SQSs are given in Table 2.19 with respect to the considered exposure scenarios.

Table 2.19 The Generic Values for the Exposure Parameters and Contact Rates used for Derivation of Turkish SQSs (US EPA, 2002a)

Parameters	**Residential Land Use**	**Commercial/Industrial Land Use**		**Unit**
		Outdoor Worker	**Indoor Worker**	
EF (exposure frequency)	350	225	250	days/year
ED (exposure duration)	30 (6 for non-carcinogenic effects)[1]	25	25	years
EV (event frequency)	1	1	NA	events/day
$\boldsymbol{IR_{soil}}$ (ingestion rate of soil - child)	200	NA	NA	mg/day
$\boldsymbol{IR_{soil}}$ (ingestion rate of soil - adult)	100	100	50	mg/day
$\boldsymbol{IR_{w}}$ (ingestion rate of groundwater - child)	1	NA	NA	L/day
$\boldsymbol{IR_{w}}$ (ingestion rate of groundwater - adult)	2	2	2	L/day
InhR (inhalation rate) [2]	20	20	20	m^3/day
SA (skin surface area exposed - child)	2800	NA	NA	cm^2
SA (skin surface area exposed - adult)	5700	3300	NA	cm^2
AF (skin-soil adherence factor - child)	0.2	NA	NA	mg/cm^2-event
AF (skin-soil adherence factor - adult)	0.07	0.2	NA	mg/cm^2-event
BW (body weight - child)	15	NA	NA	kg
BW (body weight - adult)	70	70	70	kg
LT (lifetime)	70	70	70	years

[1] A child is defined as an individual between one and six years of age.

[2] Residential inhalation exposure to children and adults are evaluated by using the *RfC* toxicity criterion, which is based on an inhalation rate of 20 m^3/day. No comparable toxicity criterion specific to childhood exposures is currently available.

2.2.3.4 Generic Soil Characteristics

Site characteristics (i.e., soil characteristics, hydrogeological characteristics, meteorological conditions) define the transport of chemicals in different environmental mediums. Thus, typical -at the same time conservative- site conditions should be specified for derivation of conservative SQSs. The site characteristics listed in Table 2.20, which vary with respect to soil characteristics and meteorological conditions of a site, are needed to be specified for derivation of SQSs.

Table 2.20 Generic Site Characteristics needed to be specified for Derivation of Turkish SQSs

Parameters	**Significance**
pH (soil pH)	Affects mobility of metals and ionizing organics, because K_d and K_{oc} of some substances change as a function of *pH*.
f_{oc} (fraction of organic carbon in soil)	Related to the soil organic matter content which determines the phase partitioning of contaminants.
ρ_b (dry soil bulk density)	Measure of the dry-weight of the soil per unit volume.
ρ_s (soil particle density)	Measure of the weight of the soil solids only per unit volume.
n (total soil porosity)	Refers to the fraction of bulk soil volume occupied by pores (i.e., by air and water).
θ_w (water filled soil porosity)	Refers to the amount of soil pore space occupied by water.
θ_a (air filled soil porosity)	Refers to the amount of soil pore space occupied by air.
Q/C_{vol} (air dispersion factor for volatiles)	Used to estimate volatilization factor (*VF*) that relates the concentration of contaminant in soil with the concentration of volatiles in the air. Depends on the source size.
Q/C_{wind} (air dispersion factor for fugitive dusts)	Used to estimate particulate emission factor (*PEF*) that relates the concentration of contaminant in soil with the concentration of dust particles in the air. Depends on the source size.
V (fraction of vegetative cover)	Fraction of continuous vegetative cover. Used to estimate *PEF.*
U_m (mean annual wind speed at 10m)	Annual average wind speed at 10m above ground. Used to estimate *PEF*.
U_t (equivalent threshold value of wind speed at 10m)	Equivalent threshold value of wind speed at 10m. Used to estimate *PEF.*

In order to calculate the SQSs for inhalation of fugitive dusts and inhalation of volatiles, the volatilization factor (*VF*) and the particulate emission factor (*PEF*) should be determined (US EPA, 1996a). To estimate dust and volatile emissions, air dispersion models (requiring the use of meteorological data of the site) are used to develop air dispersion factors for volatiles and fugitive dusts (Q/C_{vol} and Q/C_{wind}). Q/C_{wind} is then used together with V, U_m, and U_t, which determines the amount of particulate suspension in air, to estimate *PEF* and in turn, SQSs for inhalation of fugitive dusts. On the other hand, Q/C_{vol} is used together with the generic soil parameters (i.e., f_{oc}, ρ_b, ρ_s, n, θ_w, and θ_a) to estimate *VF* and thus the SQSs for inhalation of volatiles. These soil parameters are also used to calculate the soil saturation limit (C_{sat}), which is an indication for potential existence free phase contaminant in soil. The same parameters (i.e., f_{oc}, ρ_b, ρ_s, n, θ_w, and θ_a) are also needed to be specified to represent the generic subsurface soil characteristics used to estimate contaminant release in groundwater, thus, SQSs for ingestion of groundwater pathway. Moreover, for determination of the concentration of contaminants in soil solution, soil-water partition coefficient, K_d, (for organics $K_d = K_{oc} \times f_{oc}$) is used. K_d depends on chemical properties, as well as the characteristics of soil (e.g. SOM content, soil pH).

For derivation of generic values for the air dispersion factors (Q/C_{vol} and Q/C_{wind}), an air dispersion model was run by integration of the meteorological data of seven stations distributed over Turkey. The details of the study performed for derivation of the generic values for the air dispersion factors (Q/C_{vol} and Q/C_{wind}), U_m, U_t, and V are discussed in Chapter 3 in detail.

For specification of the generic *soil characteristics* (i.e., soil texture, *pH* and f_{oc}) for Turkey, the report prepared by Eyüpoğlu (1999) for the General Directorate of Rural Services was utilized. In this report, the general soil characteristics of Turkish soils in terms of soil pH, organic matter content and texture are presented based on the analyses of more than 243,000 soil samples. Figure 2.9 showing the pH distribution of Turkish soils was plotted with respect to those analyses. As seen from the figure, 62% of Turkish soils are slightly alkaline (pH between 7.5-8.5). This is due to the calcareous parent material underlying a considerable part of Turkey (Eyüpoğlu, 1999), which can also be observed from the hydrogeological maps of Turkey given in Chapter 5. Because of this reason, the generic pH value (6.8) defined by US EPA was considered to be inapplicable for Turkey. In order to set a conservative pH value for Turkey, the effect of pH on fate and transport of chemicals has to be understood. Fundamentally, pH affects the chemical partitioning between soil and water phases, which is defined by K_d for metals and K_{oc} for organics. However, pH affects the mobility of metals and ionizing organics in different ways.

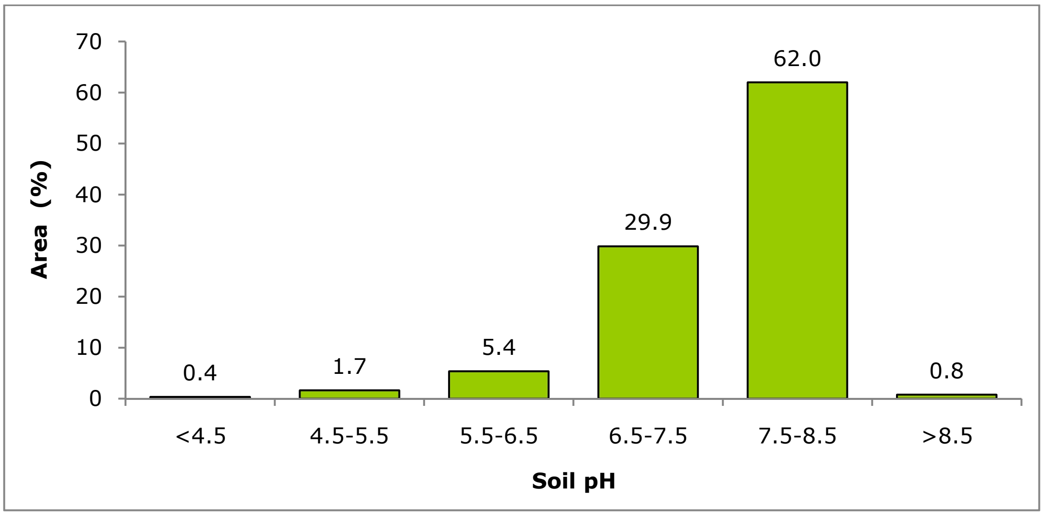


Figure 2.9 pH Distribution of Turkish Soils (Eyüpoğlu, 1999)

As mentioned previously, K_{oc} (for organics), which shows the chemical partitioning between organic carbon and water at equilibrium, is used to calculate SQSs for inhalation of volatiles and migration to groundwater pathways. Unlike non-ionizing hydrophobic organic compounds, soil-water partitioning attitude of ionizing organics are affected by soil pH. The ionizing organic compounds such as amines, carboxylic acids, and phenols exhibit different sorption behaviors under different pH conditions (US EPA, 1996a). For ionizing organic compounds, K_{oc} decreases (the chemicals tend to remain in water, instead of binding to soil) with the increasing soil pH. Since VF and in turn SQSs are directly proportional to K_{oc} values, higher pH values (lower K_{oc} values) result in generation of more conservative SQSs for inhalation of volatiles and migration to groundwater pathways.

On the other hand, for metals, soil-water partition coefficient, K_d, is used to calculate SQSs for inhalation of volatiles and migration to groundwater. Although, K_d for metals is most sensitive to various geochemical parameters and processes, it is most affected by the changes in pH (US EPA, 1996a). However, all metals designate different behaviors towards pH change. For example, K_d values for As, Ba, Be, Cd, Cr^{3+}, Hg, Ni, Ag, Th, and Zn are directly proportional to pH, whereas K_d values for Cr^{6+} and Se are indirectly proportional and for Sb and V, K_d does not depend on pH. Similar to ionizing organics, lower K_d values result in production of more conservative SQSs for inhalation of volatiles and migration to groundwater pathways.

Since the aim of Turkish generic SQSs would be to screen sites that do not need further attention, a conservative pH value had to be selected. However, due to different behaviors of ionizing organics and metals in different pH conditions, it was not possible to define a generic pH value that produces conservative SQSs for both kinds. Because of this reason, it was decided to select different pH values for ionizing organics and metals with respect to their attitude towards pH change. For this purpose, Figure 2.10, which presents the cumulative distribution of pH for Turkish soils, was plotted. From this figure, the pH values corresponding to 10th and 90th percentiles were determined as 6.7 and 8.2, respectively. For ionizing organic compounds, Cr^{6+} and Se, a generic pH of 8.2; and for the other metals (i.e. As, Ba, Be, Cd, Cr^{3+}, Hg, Ni, Ag, Tl, and Zn) a generic pH of 6.7 was selected and used for calculation of SQSs for inhalation of volatiles and migration to groundwater pathways.

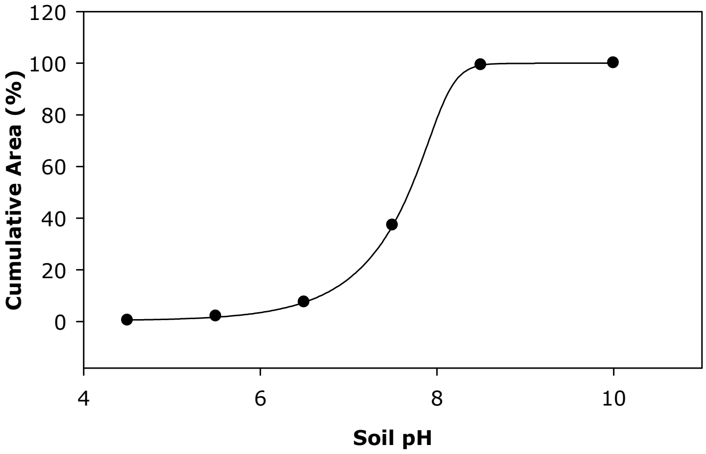


Figure 2.10 Cumulative Distribution of pH for Turkish Soils

As known, soil organic matter (SOM) is an indication of the organic constituents in soil. Natural factors, such as climate, soil parent material, land cover and/or vegetation, topography; and human-induced factors, such as land use, management and degradation affect the SOM content (Jones et al., 2004).

SOM content of Turkish soils is shown in Figure 2.11. As can be seen from the figure, about 65% of the soils in Turkey contain very low or low SOM, which clearly indicates that soils of Turkey are generally poor in terms of organic matter content. Due to the extensive vegetative cover stemming from abundant rainfall, the Black Sea Region has a relatively high organic matter content compared to other regions. On the other hand, SOM content is lower in Central and Southeast Anatolia because of weak vegetative cover, high temperatures and limited amount of precipitation (Eyüpoğlu, 1999).

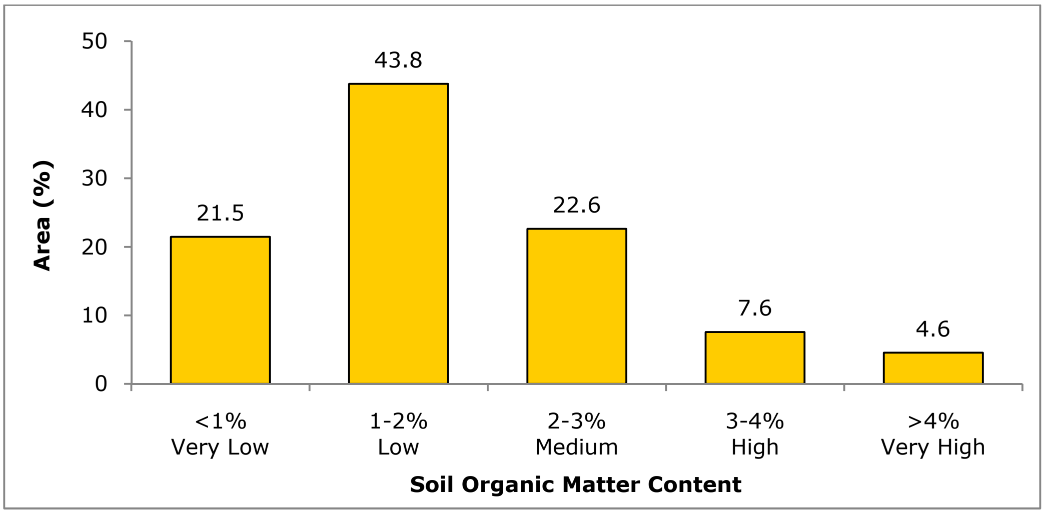


Figure 2.11 Distribution of Organic Matter Content for Turkish Soils (Eyüpoğlu, 1999)

In order to determine a conservative generic f_{oc} value for Turkey, the relationship between SOM content and SQSs should be considered. As the SOM content of soil increases, more contaminant will be adsorbed to soil which means the contaminant will be less available in soil solution for plant uptake, vaporization or migration to groundwater (UK EA, 2009). Therefore, lower SOM assumptions result in more conservative scenarios.

According to Figure 2.11, about 44% of the soils in Turkey contain low SOM (1-2%). In order to produce conservative SQSs, the generic SOM for Turkey is determined with respect to the lower end of this interval as 1%. Since soil organic carbon is referred as the major component of SOM (Jones et al., 2004), the fraction of soil organic matter is related to the soil organic carbon as given below (US EPA, 1996a):

$$f_{om}=1.724f_{oc} \tag{2.5}$$

where;

f_{om} (fraction of organic matter)
f_{oc} (fraction of organic carbon)

With use of this equation, the fraction of organic carbon for Turkish soils was calculated as 0.6%. Actually, this value is compatible with the generic value defined by US EPA (1996a) for derivation of SQSs for inhalation of volatiles pathway. On the other hand, soil organic carbon content decreases with depth and the probable range for soil organic carbon content for subsurface soils is determined as 0.1% to 0.3% by US EPA (1996a). In this regard, the generic f_{oc} value for Turkey for subsurface soils was accepted as 0.2% as it was defined by US EPA (1996a).

The other soil parameters (i.e., ρ_b, ρ_s, n, θ_w, and θ_a), which depend on the soil texture, are all related to each other. *Since VF* is most sensitive to water filled soil porosity, θ_w, which affects the air filled porosity and consequently the steady-state flux of volatile contaminants from soil (US EPA, 1996a), a conservative value (0.15) were defined for θ_w by US EPA (1996a). In fact, this value takes place between wilting point (0.09) and mean field capacity (0.20) given for Class B soils (US EPA, 1996a; Carsel et al., 1988). Class B soils are defined to have moderate hydrologic characteristics and represented by loam soil type (US EPA, 1996a). For loam soil type, the mean porosity is determined as 0.43 (US EPA, 1996a; Carsel et al., 1988). As a fact, water content of subsurface soil is always more than surface soil due to less evaporative looses from deeper depths. Therefore, a typical value of 0.30 for water content was used by US EPA to represent subsurface conditions. For Class B soils, this value takes place between the mean field capacity (0.20) and saturated volumetric water content for loam (US EPA, 1996a; Carsel et al., 1988). Considering the range of soil bulk density for surface soils (generally between 1.3 and 1.7 g/cm^3), an average value of 1.5 g/cm^3 was accepted by US EPA, which is also consistent with the soil porosity defined. Since the soil particle density for most soil mineral material is 2.65 g/cm^3, it was accepted as generic value.

As can be seen from Figure 2.12, which shows the textural characteristics of Turkish soils, more than 50% of the soils in Turkey are composed of loam. In this regard, the generic values defined by US EPA for ρ_b, ρ_s, n, θ_w, and θ_a are also applicable for Turkey. Thus, these values are also accepted as the generic values for Turkey.

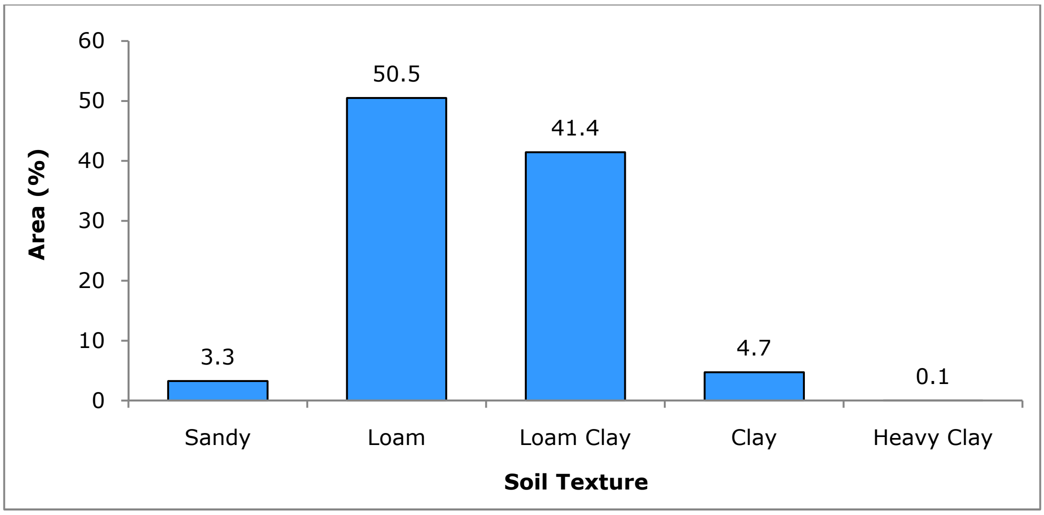


Figure 2.12 Textural Characteristics of Turkish Soils (Eyüpoğlu, 1999)

The generic values of soil characteristics were obtained as described above, and were used for derivation of generic SQSs for Turkey. All generic values used in calculations are given in Table 2.21.

Table 2.21 Site Characteristics used for Derivation of Turkish SQSs

Parameters	**Value**	**Unit**
Soil pH	6.7 and 8.2	-
f_{oc} (fraction of organic carbon in soil)	0.006 [a]	g/g
ρ_b (dry soil bulk density)	1.5	kg/L
ρ_s (soil particle density)	2.65	kg/L
n (total soil porosity)	$1-(\rho_b/\rho_s)$	L_{pore}/L_{soil}
θ_w (water filled soil porosity)	0.15 [b]	L_{water}/L_{soil}
θ_a (air filled soil porosity)	$n-\theta_w$	L_{air}/L_{soil}
Q/C_{vol} (air dispersion factor for volatiles)	27.61 [c]	g/m^2-s per kg/m^3
Q/C_{wind} (air dispersion factor for fugitive dusts)	59.24 [d]	g/m^2-s per kg/m^3
V (fraction of continuous vegetative cover)	0.2	unitless
U_m (mean annual wind speed at 10m)	3.0	m/s
U_t (equivalent threshold value of wind speed at 10m)	8.28	m/s
$F(x)$ (function dependent on U_m/U_t derived using Cowherd et al. (1985))	6.67×10^{-2}	unitless

[a] To be conservative, fraction of soil organic carbon is taken as 0.006 g/g for inhalation pathway, whereas it is taken as 0.002 g/g for migration to groundwater pathway.

[b] To be conservative, water filled soil porosity is taken as 0.15 for inhalation pathway, whereas it is taken as 0.30 for migration to groundwater pathway.

[c] For residential scenario (source size: 0.01ha) 27.61 g/m^2-s per kg/m^3; for industrial/commercial scenario (source size: 1ha) 8.96 g/m^2-s per kg/m^3.

[d] For residential scenario (source size: 0.01ha) 59.24 g/m^2-s per kg/m^3; for industrial/commercial scenario (source size: 1ha) 19.81 g/m^2-s per kg/m^3.

2.2.3.5 Physical-Chemical Data

As contaminants are released into the environment, physical-chemical characteristics determine the environmental fate and transport of pollutants. Therefore, various physical-chemical properties of contaminants should be known, in order to estimate the concentrations of chemicals in different mediums (i.e., air water and soil).

With respect to the considered exposure pathways in the generic scenario, the chemical-specific properties required to derive generic SQSs and their significance are given in Table 2.22. Among these parameters, K_{oc}, K_d, H', S, D_i, and D_w are used for estimating the volatilization factor (*VF*), saturation concentration (C_{sat}) and the partitioning between soil and groundwater. *MP* of a contaminant should be known in order to define the physical state of contaminant at typical soil temperatures. Physical state of the contaminant is important for assessing the existence of free liquid phase (i.e., non-aqueous phase liquid (NAPL)) contamination in soil. Hence, these parameters are required to derive the SQSs for inhalation of volatiles and migration to groundwater pathways.

Table 2.22 Physical and Chemical Properties of Contaminants (US EPA, 1989)

Parameters	**Unit**	**Significance**
K_{oc} (soil organic carbon partition coefficient)	L/kg	Refers to chemical partitioning between organic carbon and water at equilibrium. The higher the K_{oc}, the more likely a chemical is to bind to soil or sediment than to remain in water.
K_d (soil-water partition coefficient)	L/kg	Refers to chemical partitioning between soil and water. The higher the K_d, the more likely a chemical is to bind to soil or sediment than to remain in water.
H' (Henry's law constant)	unitless	Refers to chemical partitioning between air and water at equilibrium. The higher the Henry's Law constant, the more likely a chemical is volatilize than to remain in water.
S (solubility in water)	mg/L	Refers to an upper limit on a chemical's dissolved concentration in water at a specified temperature.
D_i (diffusivity in air)	cm^2/s	Refers to the movement of a molecule in a gas medium as a result of differences in concentration. The higher the diffusivity, the more likely a chemical is to move in response to concentration gradients.
D_w (diffusivity in water)	cm^2/s	Refers to the movement of a molecule in a liquid as a result of differences in concentration. The higher the diffusivity, the more likely a chemical is to move in response to concentration gradients.
MP (melting point)	^oC	Refers to the temperature at which the physical state of chemical changes from solid to liquid. Used to determine the physical state of organic chemicals at typical soil temperatures
ABS_{GI} (gastro intestinal absorption factor)	unitless	Used to adjust the oral reference dose (RfD) and cancer slope factor (SF) for a contaminant to dermal dose. If gastrointestinal absorption is greater than 50%, no adjustment is made.
ABS_d (dermal absorption factor)	unitless	Refers to the average dermal absorption values across a range of soil types, loading rates, and chemical concentrations.

The sources of information were reviewed for compilation of the physical-chemical parameters required for development of SQSs. The Risk Assessment Information System (RAIS) online database (URL 3) was determined as a reputable information source to gather the chemical-specific data needed.

The RAIS online database, which includes toxicological and chemical-specific data, is developed by Oak Ridge National Laboratory (ORNL) in 1996 with the support of the US Department of Energy (URL 3). The RAIS provides "the risk assessment tools, such as guidance documents, tutorials, databases, historical information and risk models, to users from 45 State Governments, many Federal agencies and over 60 countries" (URL 3). In the RAIS, the main source of chemical-specific information is EPI Suite (the database program developed by the US EPA) (URL 2) and all information presented by the RAIS complies with the US EPA guidance (URL 3). Therefore, it was considered as a reliable source for providing the chemical-specific data to be used in derivation of Turkish SQSs. However, RAIS presents K_{oc} (for organics) and K_d (for inorganics) only at a pH of 6.8 that is compatible with US EPA's methodology. For this reason, K_{oc} and K_d values for the pH dependent contaminants were compiled from Supplemental Guidance of US EPA (2002a).

As a result, the physical-chemical values for more than 800 substances were compiled in the MS Excel based data library to facilitate the access to the information required for development of SQSs. This library was integrated with the computational tool (described in Chapter 4) that was developed for calculating generic and site-specific SQSs. Thus, any upgrade made in chemical-specific values can be monitored from the RAIS and reflected to the data library of the computational tool to renew SQSs accordingly.

2.2.3.6 Toxicological Data (Human Health Benchmarks)

As mentioned in Section 2.1.1.3, risk based SQSs are derived based on toxicological data. The chemical-specific toxicological data, which defines the human health benchmarks, used for derivation of generic SQSs are listed in Table 2.23. Oral reference dose (RfD_o) and inhalation reference concentration (RfC) are used to estimate chronic non-carcinogenic health effects, while oral slope factor (SF_o) and inhalation unit risk factor (URF) are used to estimate risks for carcinogenic effects (URL 7). SQSs for ingestion and inhalation pathways are derived by use of these toxicity parameters.

Since the toxicological data presented in the RAIS database are compatible with the US EPA methodology for development of soil quality criteria (URL 3), the toxicity data to be used for derivation of Turkish SQSs are provided from the RAIS. This database contains toxicity information for more than 1000 chemicals which are reviewed and updated regularly.

Table 2.23 Human Health Benchmarks used for Derivation of Turkish SQSs

Parameters	**Unit**	**Significance**
SF_o (oral slope factor)	$(mg/kg\text{-}d)^{-1}$	Refers to an upper-bound on the increased cancer risk from a lifetime exposure to an agent by ingestion. This estimate, usually expressed in units of proportion (of a population) affected per mg of substance/kg body weight-day.
RfD_o (oral reference dose)	mg/kg-d	Refers to an estimate of a daily oral exposure to human population that is likely to be without an appreciable risk of deleterious effects during lifetime and expressed as expressed in units of mg of substance/kg body weight-day.
URF (inhalation unit risk factor)	$(\mu g/m^3)^{-1}$	Refers to the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air.
RfC (inhalation reference concentration)	mg/m^3	Refers to an estimate of a continuous inhalation exposure to human population that is likely to be without an appreciable risk of deleterious effects during lifetime.
C_w (target soil leachate concentration)	mg/L	Refers to the allowable maximum concentration level for drinking water.

The toxicological data presented by the RAIS are gathered from "the US EPA's Integrated Risk Information System (IRIS), EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs), and other sources such as the California EPA (CalEPA), the Agency for Toxic Substances and Disease Registry (ATSDR) and the Health Effects Assessment Summary Tables (HEAST) with respect to the hierarchy stated in the OSWER Directive 9285.7-53" (US EPA, 2003). Any upgrade in the toxicological values is indicated in the RAIS database separately, thus it is easy to monitor the latest amendments and transfer them to the data library of the computational tool to renew SQSs accordingly.

On the other hand, target leachate concentration in soil (C_w) is used for derivation of the SQSs for migration to groundwater pathway. Because groundwater is used frequently for drinking purposes in Turkey, drinking water standards given in TS-266 Water Intended for Human Consumption (TSE, 2005) published by Turkish Standardization Institute were accepted as the target soil leachate concentration. For the compounds that are not included in TS-266, WHO's drinking water standards (WHO, 2008) were used. For the compounds that are not included in any of these standards, health based limits (*HBL*), which are calculated based on 10^{-6} target risk level or a HQ of 1 (the details of calculation procedure is given in Section 2.2.4.3), were used.

2.2.4 Calculation of the Generic SQSs

US EPA's "Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites" (2002a), "Soil Screening Guidelines: Technical Background Document" (1996a) and "Soil Screening Guidance: User's Guide" (1996b) were the primary documents utilized for development of Turkish generic SQSs. The final versions of the risk based equations that take place in US EPA's "Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites" (2002a) are used for calculations. All of these equations are based on chronic exposures and reasonable maximum exposure (RME) assumption (US EPA, 1996b).

Generic SQSs were calculated for three different land use scenarios (residential scenario, commercial/industrial scenario: outdoor worker, and commercial/ industrial scenario: indoor worker) by use of US EPA's standardized sets of equations. The exposure pathways and the potential receptors considered in each of these land use scenarios are summarized in Table 2.24.

For each pathway (combined soil ingestion and dermal contact, inhalation of fugitive particles, inhalation of volatiles, and ingestion of contaminated groundwater), soil concentrations are calculated for the carcinogenic risks and for the non-carcinogenic health effects of chemicals. In other words, pathway specific soil concentrations of carcinogenic and non-carcinogenic chemicals that correspond to the target cancer risk level (10^{-6}) and target hazard quotient (1), respectively, are calculated for each compound. The lowest of these two concentrations (i.e., soil concentration calculated considering the carcinogenic risks and soil concentration calculated considering the non-carcinogenic effects of a substance) is set as the generic SQS. For example; SQS_1^c denoting the *carcinogenic SQS* and SQS_1^{nc} denoting the *non-carcinogenic SQS* for ingestion-dermal contact pathway were calculated and the lower of these two values is considered as the SQS_1 for ingestion-dermal contact pathway (subscript indicating the pathway) as shown in Table 2.25.

Table 2.24 Generic Land Use Scenarios and Relevant Pathways of Concern

	Residential Scenario	**Commercial/Industrial Scenario: Outdoor Worker**	**Commercial/Industrial Scenario: Indoor Worker**
Potential Receptor	child, adult	adult	adult
Direct Ingestion	√	√	√
Dermal Contact	√	√	-
Inhalation of Volatiles	√	√	-
Inhalation of Fugitive Particulates	√	√	-
Migration to Groundwater	√	√	√

Table 2.25 Determination of the SQSs Considering the Carcinogenic Risks and Non-Carcinogenic Health Effects of a Contaminant

Ingestion-Dermal (mg/kg)		**Inhalation of Volatiles (mg/kg)**		**Inhalation of Fugitive Particulates (mg/kg)**		**Migration to Groundwater (mg/kg)**	
SQS_1^c	SQS_1^{nc}	SQS_2^c	SQS_2^{nc}	SQS_3^c	SQS_3^{nc}	SQS_4^c	SQS_4^{nc}
$\boldsymbol{SQS_1}$		$\boldsymbol{SQS_2}$		$\boldsymbol{SQS_3}$		$\boldsymbol{SQS_4}$	

* SQS^c (*SQS* calculated considering carcinogenic risks), SQS^{nc} (*SQS* calculated considering non-carcinogenic health effects); subscripts indicating the pathway.

The equations used for calculating the pathway specific SQSs are presented in the following sections. The exposure parameters and the contact rates are given for residential land use scenario. In order to calculate the SQSs for commercial/ industrial land use scenarios, Table 2.19 and Table 2.24 should be consulted. The example SQS calculations can be seen in Appendix-C.

2.2.4.1 Soil Ingestion and Dermal Absorption

The equations used to calculate SQS for combined ingestion-dermal absorption exposure pathway are given below. Equation 2.6 is used for exposure to carcinogenic contaminants. For carcinogenic compounds, duration of exposure is vital because the toxicity criteria are based on "lifetime average daily dose" (US EPA, 1996b). Hence, the total dose received is averaged over a lifetime of 70 years. Besides, the maximum exposure duration is assumed to be 30 years which is considered as the high-end period for an individual to live in the same residence from childhood to adulthood (US EPA, 1996b). Because exposure to soil is higher during childhood and decreases with age, time-weighted average soil ingestion rate (Equation 2.7) is used (US EPA, 1996b).

Due to the variation in skin surface area, skin-soil adherence factor and body weight for children and adults, age-adjusted dermal factor (*SFS*) is used (See Equation 2.8). Equation 2.10 is used to calculate SQSs for exposure to non-carcinogenic contaminants. In this equation, it is assumed that individuals are exposed to contaminants commonly during childhood by inadvertent ingestion of soil (US EPA, 1996b). Since no toxicity data are presently available to evaluate dermal exposures to contaminants, oral toxicity values are extrapolated by use of Equations 2.9 and 2.11.

Table 2.26 Equations to Calculate SQSs for Soil Ingestion - Dermal Contact Pathway

$$SQS_1^c\ (mg/kg)=\frac{TR\times AT\times 365\,d/yr}{\left(EF\times 10^{-6}\,kg/mg\right)\left[\left(SF_o\times IF_{soil/adj}\right)+\left(SF_{ABS}\times SFS\times ABS_d\times EV\right)\right]} \tag{2.6}$$

where;

SQS_1^c (carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
EF (exposure frequency)	350	day/year
SF_{ABS} (dermally adjusted slope factor)	chemical-specific [a]	$(mg/kg\text{-}day)^{-1}$
SFS (age-adjusted dermal factor)	360 [b]	mg-year/kg-event
ABS_d (dermal absorption factor)	chemical-specific [c]	unitless
EV (event frequency)	1	event/day
SF_o (oral slope factor)	chemical-specific [c]	$(mg/kg\text{-}day)^{-1}$
$IF_{soil/adj}$ (age-adjusted soil ingestion factor)	114	mg-year/kg-day

[a] See Equation 2.9; [b] See Equation 2.8; [c] See Appendix-E.

$$IF_{soil/adj}=\left[\frac{IR_{soil/1\text{-}6}\times ED_{1\text{-}6}}{BW_{1\text{-}6}}\right]+\left[\frac{IR_{soil/7\text{-}31}\times ED_{7\text{-}31}}{BW_{7\text{-}31}}\right] \tag{2.7}$$

where;

$IF_{soil/adj}$ (age-adjusted soil ingestion factor)	-	mg-year/kg-day
$IR_{soil/1\text{-}6}$ (ingestion rate of soil age 1-6)	200	mg/day
$IR_{soil/7\text{-}31}$ (ingestion rate of soil age 7-31)	100	mg/day
$ED_{1\text{-}6}$ (exposure duration during ages 1-6)	6	year
$ED_{7\text{-}31}$ (exposure duration during ages 7-31)	24	year
$BW_{1\text{-}6}$ (average body weight from ages 1-6)	15	kg
$BW_{7\text{-}31}$ (average body weight from ages 7-31)	70	kg

$$SFS=\left[\frac{SA_{1\text{-}6}\times AF_{1\text{-}6}\times ED_{1\text{-}6}}{BW_{1\text{-}6}}\right]+\left[\frac{SA_{7\text{-}31}\times AF_{7\text{-}31}\times ED_{7\text{-}31}}{BW_{7\text{-}31}}\right] \tag{2.8}$$

where;

SFS (age-adjusted dermal factor)	-	mg-year/kg-event
$SA_{1\text{-}6}$ (skin surface area exposed-child)	2800	cm^2
$SA_{7\text{-}31}$ (skin surface area exposed-adult)	5700	cm^2
$AF_{1\text{-}6}$ (skin-soil adherence factor-child)	0.2	mg/cm^2-event
$AF_{7\text{-}31}$ (skin-soil adherence factor-adult)	0.07	mg/cm^2-event
$ED_{1\text{-}6}$ (exposure duration-child)	6	year
$ED_{7\text{-}31}$ (exposure duration-adult)	24	year
$BW_{1\text{-}6}$ (body weight-child)	15	kg
$BW_{7\text{-}31}$ (body weight-adult)	70	kg

Table 2.26 Equations to Calculate SQSs for Soil Ingestion-Dermal Contact Pathway (cont'd)

$$SF_{ABS}=\frac{SF_o}{ABS_{GI}} \qquad (2.9)$$

where;

SF_{ABS} (dermally adjusted slope factor)	-	$(\text{mg/kg-day})^{-1}$
SF_o (oral slope factor)	chemical-specific [a]	$(\text{mg/kg-day})^{-1}$
ABS_{GI} (gastro-intestinal absorption factor)	chemical-specific [a]	unitless

[a] See Appendix-E.

$$SQS_1^{nc}=\frac{THQ\times BW\times AT\times 365\ d/yr}{\left(EF\times ED\times 10^{-6} kg/mg\right)\left[\left(\frac{1}{RfD_o}\times IR\right)+\left(\frac{1}{RfD_{ABS}}\times AF\times ABS_d\times EV\times SA\right)\right]} \qquad (2.10)$$

where;

SQS_1^{nc} (non-carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
THQ (target hazard quotient)	1	unitless
BW (body weight)	15	kg
AT (averaging time)	6 [a]	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	6	year
RfD_o (oral reference dose)	chemical-specific [b]	mg/kg-day
IR (soil ingestion rate)	200	mg/day
RfD_{ABS} (dermally-adjusted reference dose)	chemical-specific [c]	mg/kg-day
AF (skin-soil adherence factor)	0.2	mg/cm^2-event
ABS_d (dermal absorption factor)	chemical-specific [b]	unitless
EV (event frequency)	1	event/day
SA (skin surface area exposed)	2800	cm^2

[a] For non-carcinogens, averaging time equals exposure duration; [b] See Appendix-E; [c] See Equation 2.11

$$RfD_{ABS}=RfD_o\times ABS_{GI} \qquad (2.11)$$

where;

RfD_{ABS} (dermally-adjusted reference dose)	-	mg/kg-day
RfD_o (oral reference dose)	chemical-specific [a]	mg/kg-day
ABS_{GI} (gastro-intestinal absorption factor)	chemical-specific [a]	unitless

[a] See Appendix-E.

2.2.4.2 Inhalation of Fugitive Particulates and Volatiles

Inhalation risk from fugitive particulates results from contaminant concentrations in the surface soil horizon (e.g., the top 2 cm) (US EPA, 1996a). On the other hand, the entire column of contaminated soil can contribute to volatile emissions at a site (US EPA, 1996a). Thus, contaminant concentrations in subsurface soils are of primary concern for quantifying the risk from volatile emissions (US EPA, 1996a). Because of these reasons, different sampling strategies are used for surface soil and subsurface soil during generic risk analysis. Consequently, SQSs for inhalation of fugitive particulates and inhalation of volatile contaminants pathways are calculated using different equations. In the following sections, the equations used to calculate SQSs for inhalation of fugitive particulates and inhalation of volatiles are presented.

Inhalation of the fugitive particulates pathway is of concern for certain metals but does not appear to be of concern for organic compounds (US EPA, 1996a). Furthermore, for organic compounds, the SQSs calculated for ingestion-dermal absorption pathway is much stringent than the SQSs calculated for inhalation of fugitive particulates. Since both ingestion-dermal absorption and inhalation of fugitive particulates pathways are important for surface soils, SQS for ingestion-dermal absorption pathway is necessarily protective for this media (US EPA, 1996b). Therefore, SQSs for the fugitive particulates pathway are only presented for inorganic compounds. On the other hand, SQSs for the inhalation of volatiles pathway are not provided for inorganic compounds, because these chemicals are not volatile (mercury is an exception since it is volatile) (US EPA, 1996a).

2.2.4.2.1 Inhalation of Fugitive Particulates

The equations used to calculate the SQSs for inhalation of fugitive particulates pathway are presented in Equations 2.12, 2.13 and 2.14. Equation 2.12 is used for exposure to carcinogenic contaminants and Equation 2.13 is used for exposure to non-carcinogenic contaminants. In both of these equations, particulate emission factor (*PEF*), which represents an estimate of the relationship between soil contaminant concentrations and the concentration of the contaminants in air as a consequence of particle suspension, is used (US EPA, 2002a). *PEF* shows the annual average particulate matter emission resulting from wind erosion. As can be seen from Equation 2.14, region-specific parameters such as fraction of vegetative cover (*V*), mean annual wind speed (U_m) and dispersion factor (*Q/C*) are used to calculate *PEF*. *Q/C* is a factor representing the dispersion of fugitive dust emissions in air (the methodology used for derivation of *Q/C* factor is described in greater detail in Chapter 3).

Table 2.27 Equations to Calculate SQSs for Inhalation of Fugitive Dusts Pathway

$$SQS_2^c=\frac{TR\times AT\times 365\ d/yr}{URF\times EF\times ED\times\left[\frac{1}{PEF}\right]} \tag{2.12}$$

where;

SQS_2^c (carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	chemical-specific [a]	$(mg/m^3)^{-1}$
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
PEF (particulate emission factor)	$2.33x10^9$ [b]	m^3/kg

[a] See Appendix-E. ; [b] See Equation 2.14 (For residential scenario (source size: 0.01ha) $2.33x10^9$ m^3/kg; for industrial/commercial scenario (source size: 1ha) $7.80x10^8$ m^3/kg).

$$SQS_2^{nc}=\frac{THQ\times AT\times 365\ d/yr}{EF\times ED\times\left(\frac{1}{RfC}\times\frac{1}{PEF}\right)} \tag{2.13}$$

where;

SQS_2^{nc} (non-carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30[a]	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfC (inhalation reference concentration)	chemical-specific [b]	mg/m^3
PEF (particulate emission factor)	$2.33x10^9$ [c]	m^3/kg

[a] For non-carcinogens, averaging time equals exposure duration. ; [b] Appendix-E. ; [c] See Equation 2.14 (For residential scenario (source size: 0.01ha) $2.33x10^9$ m^3/kg; for industrial/commercial scenario (source size: 1ha) $7.80x10^8$ m^3/kg).

$$PEF=Q/C_{wind}\times\frac{3600\ s/h}{0.036\times(1-V)\times(U_m/U_t)^3\times F(x)} \tag{2.14}$$

where;

PEF (particulate emission factor)	**$2.33x10^9$**	m^3/kg
Q/C_{wind} (air dispersion factor for fugitive dusts)	59.24 [a]	$(g/m^2\text{-}s)/(kg/m^3)$
V (fraction of continuous vegetative cover)	0.2 (20%)	unitless
U_m (mean annual wind speed)	3.0	m/s
U_t (equivalent threshold value of wind speed at 10m)	8.28	m/s
F(x) (Function dependent on U_m/U_t derived using Cowherd et al.)	$6.67x10^{-2}$	unitless

[a] For residential scenario (source size: 0.01ha) 59.24 g/m^2-s per kg/m^3; for industrial/commercial scenario (source size: 1ha) 19.81 g/m^2-s per kg/m^3.

2.2.4.2.2 Inhalation of Volatiles

The equations used to calculate SQSs for inhalation of volatiles are given in Equations 2.15, 2.16, 2.17 and 2.19. Equation 2.15 is used for exposure to carcinogenic compounds and Equation 2.16 is used for exposure to non-carcinogenic compounds. In both of these equations, soil to air volatilization factor (*VF*), which represents an estimate of the relationship between soil contaminant concentrations and the concentration of the contaminants in air as a consequence of volatilization, is used (US EPA, 2002a). As can be seen from Equations 2.17 and 2.18, chemical and generic site parameters are used to calculate *VF*. One of these generic site parameters is *Q/C*, which is estimated by use of air dispersion modeling, representing the dispersion of volatile emissions in ambient air (the methodology used for derivation of *Q/C* factor is described in greater detail in Chapter 3).

Table 2.28 Equations to Calculate SQSs for Inhalation of Volatiles Pathway

$$SQS_3^c = \frac{TR \times AT \times 365\ d/yr}{URF \times EF \times ED \times \left(\frac{1}{VF}\right)} \qquad (2.15)$$

where;

$\boldsymbol{SQS_3^c}$ (carcinogenic SQS for inhalation of volatile contaminants)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	chemical-specific [a]	$(mg/m^3)^{-1}$
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
VF (soil to air volatilization factor)	chemical-specific [b]	m^3/kg

[a] See Appendix-E. ; [b] See Equation 2.17.

$$SQS_3^{nc} = \frac{THQ \times AT \times 365\ d/yr}{EF \times ED \times \left(\frac{1}{RfC} \times \frac{1}{VF}\right)} \qquad (2.16)$$

where;

$\boldsymbol{SQS_3^{nc}}$ (non-carcinogenic SQS for inhalation of volatile contaminants)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30[a]	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfC (inhalation reference concentration)	chemical-specific [b]	mg/m^3
VF (soil to air volatilization factor)	chemical-specific [c]	m^3/kg

[a] For non-carcinogens, averaging time equals exposure duration.; [b] See Appendix-E.; [c] See Equation 2.17.

Table 2.28 Equations to Calculate SQSs for Inhalation of Volatiles Pathway (cont'd)

$$VF=\frac{Q/C_{vol}\times(3.14\times D_A\times T)^{1/2}\times\left(10^{-4}\ m^2/cm^2\right)}{(2\times\rho_b\times D_A)} \tag{2.17}$$

$$D_A=\frac{\left[\left(\theta_a^{10/3}D_iH'+\theta_w^{10/3}D_w\right)/n^2\right]}{\rho_bK_d+\theta_w+\theta_aH'} \tag{2.18}$$

where;

VF (soil to air volatilization factor)	chemical-specific	m^3/kg
D_A (apparent diffusivity)	chemical-specific	cm^2/s
Q/C_{vol} (air dispersion factor for volatiles)	27.61[a]	$(g/m^2\text{-}s)/(kg/m^3)$
T (exposure interval)	9.5×10^8	s
ρ_b (dry soil bulk density)	1.5	g/cm^3
θ_a (air filled soil porosity)	$n-\theta_w$	cm^3/cm^3
n (total soil porosity)	$1-(\rho_b/\rho_s)$	cm^3/cm^3
θ_w (water filled soil porosity)	0.15	cm^3/cm^3
ρ_s (soil particle density)	2.65	g/cm^3
D_i (diffusivity in air)	chemical-specific [b]	cm^2/s
H' (Henry's law constant)	chemical-specific [b]	unitless
D_w (diffusivity in water)	chemical-specific [b]	cm^2/s
K_d (soil-water partition coefficient)	chemical-specific [b,c]	cm^3/g
K_{oc} (soil organic carbon partition coefficient)	chemical-specific [b]	cm^3/g
f_{oc} (fraction of organic carbon in soil)	0.006	g/g

[a] For residential scenario (source size: 0.01ha) 27.61 g/m^2-s per kg/m^3; for industrial/commercial scenario (source size: 1ha) 8.96 g/m^2-s per kg/m^3.

[b] See Appendix-E.; [c] For organics $K_d=K_{oc}\times f_{oc}$, for metals K_d value is used.

2.2.4.2.3 Soil Saturation Concentration

The soil saturation concentration (C_{sat}) corresponds to the contaminant concentration in soil at which the absorptive limits of the soil particles, dissolution limit of soil-water and volatilization limit of soil-air have been reached (US EPA, 1996a). In other words, solid adsorptive surface sites, soil pore water and soil pore air, are saturated with chemical at C_{sat}. Therefore, above this concentration, the soil contaminant may be present in free phase (NAPLs).

Chemical-specific C_{sat} concentrations must be calculated by use of Equation 2.19 and compared with each volatile inhalation SQS (i.e., carcinogenic and non-carcinogenic SQSs) to assess potential presence of NAPLs because Henry's law is not applicable when free-phase contaminants are present (US EPA, 1996a).

In other words, an accurate VF cannot be estimated when SQSs for inhalation of volatiles is above C_{sat}. When calculating SQSs for volatile inhalation pathway, C_{sat} values also should be calculated using the same generic soil characteristics used to calculate SQSs (i.e., bulk density, average water content, and organic carbon content) (US EPA, 1996a).

For compounds that are liquid at ambient soil temperature, if the volatile inhalation SQS is above C_{sat}, then C_{sat} is set as the SQS for this exposure pathway. Because at C_{sat} the emission flux from soil to air for a chemical reaches an asymptotic value and volatile emissions will not increase above this level, no matter how much more chemical is added to the soil (US EPA, 1996a). This means that there is no volatile inhalation risk for that chemical regardless of the concentration of chemical in soil. However, this situation indicates potential existence of NAPL which should be considered thoroughly against potential risks to groundwater (US EPA, 1996b).

On the other hand, "for organic compounds that are solid at ambient soil temperature, concentrations above Csat do not pose a significant inhalation risk or a potential for NAPL occurrence" (US EPA, 1996b). Because of this reason, SQSs for this pathway can be neglected.

Table 2.29 Equation to Calculate Soil Saturation Concentration

$$C_{sat}=\frac{S}{\rho_b}\left[K_d\rho_b+\theta_w+H^{'}\theta_a\right] \qquad (2.19)$$

where;

C_{sat} (soil saturation concentration)	-	mg/kg
S (solubility in water)	chemical-specific [a]	mg/L
ρ_b (dry soil bulk density)	1.5	kg/L
K_d (soil-water partition coefficient)	chemical-specific [a.b]	L/kg
K_{oc} (soil organic carbon partition coefficient)	chemical-specific [a]	L/kg
f_{oc} (fraction of organic carbon in soil)	0.006 (%0.6)	g/g
θ_w (water filled soil porosity)	0.15	cm^3/cm^3
$H^{'}$ (Henry's law constant)	chemical-specific [a]	unitless
θ_a (air filled soil porosity)	$n-\theta_w$	cm^3/cm^3
n (total soil porosity)	$1-(\rho_b/\rho_s)$	cm^3/cm^3
ρ_s (soil particle density)	2.65	g/cm^3

[a] See Appendix-E.; [b] For organics $K_d=K_{oc}\times f_{oc}$, for metals K_d value is used.

2.2.4.3 Migration to Groundwater

When deriving the SQSs for migration to groundwater pathway, the potential for leaching of contaminants through soil to an underlying potable aquifer is considered (US EPA, 1996b). A standard linear equilibrium soil/water partition equation is used to estimate contaminant release in soil leachate (Equation 2.20) and to calculate the SQSs for this exposure pathway (US EPA, 1996a). In fact, SQSs are back-calculated from acceptable groundwater concentration which is represented by target soil-leachate concentration, C_w (US EPA, 1996a).

In Turkey, groundwater is frequently used for drinking purposes. Because of this reason, the acceptable groundwater concentration was set according to the standards of Turkish Standardization Institute, TS-266 Water Intended for Human Consumption Standards (TSE, 2005). For the compounds that are not included in TS-266, WHO's drinking water standards (WHO, 2008) were used. For the compounds that are not covered by any of these standards, health based limits (*HBL*), which are risk based drinking water concentrations, were calculated and used. The equations used to calculate carcinogenic and non-carcinogenic *HBLs* are presented in Equations 2.21 and 2.23. While calculating carcinogenic *HBL*, age-adjusted drinking water ingestion rate is included (Equation 2.22).

The dilution factor represents the reduction in soil leachate contaminant concentrations by mixing in the aquifer, expressed as the ratio of leachate concentration to the concentration in ground water at the receptor point (e.g., drinking water well) (US EPA, 1996a). As a conservative approach, the equations used for development of *DF* does not account for attenuation (e.g., adsorption and degradation) of contaminants. *DF* can be determined by use of groundwater simulation models (US EPA, 1996a) or use of a simple water-balance equation (given in Equation 2.242.20). A detailed discussion of the general approach to determination of *DF* and the related studies performed by the US EPA are presented in Section 5.1.1. However, due to insufficient field data, a generic *DF* could not been estimated for Turkey. Instead, the generic *DF* of 10, which is an over-conservative and at the same time a reasonable value compared to other countries' generic DF values (e.g., the Netherlands and Norway using a generic DF of 10; Canada, 50; and the US EPA, 20 for a source size of 0.2ha and 10 for a source size of 12ha), was assumed. As a consequence, SQSs are calculated for two *DF* values, 1 and 10. It is decided to used a *DF* of 1, in case the depth to aquifer is less than 3 m (Çelik et al., 2009), or aquifer is fractured or karstic, or source area is greater than or equal to 10 ha; in all other conditions *DF* is accepted as 10 (Ünlü et al., 2009).

By multiplying the acceptable ground water concentration (TS-266, WHO or *HBL* standards) by the *DF*, a target leachate concentration, C_w is obtained. If DF is taken as 10, for an acceptable groundwater concentration of 0.05 mg/L, the target soil leachate concentration will be found as 0.05 x 10 = 0.5 mg/L (US EPA, 1996a). If *DF* assumed to be 1, it means the worst case scenario applies and no dilution or attenuation between the source and the receptor well is expected. Thus, target soil leachate concentration equals to the acceptable groundwater concentration.

To summarize, soil contaminant concentration, SQS in mg/kg, is calculated by use of the corresponding target soil-leachate concentration, C_w in mg/L (Equation 2.20). In the end, the SQSs calculated are compared with C_{sat}, to check for the existence of free phase substance. If the SQS for migration to groundwater pathway is higher than C_{sat}, then C_{sat} is set as the SQS for this exposure pathway.

2.2.5 Special Case Chemicals

SQSs for most of the chemicals can be derived readily by using the equations given in Section 2.2.4, however, for some chemicals particular attention is needed (URL 5). In the following sections, the chemicals that need further attention in derivation of SQSs are discussed. These chemicals are cadmium, chromium, lead, PCBs, and dioxins.

2.2.5.1 Cadmium

For cadmium, two different RfD_o values are presented by IRIS; one of them is based on cadmium intake by water (0.0005 mg/kg-day) and the other is based on the intake by food (0.001 mg/kg-day) (URL 3; URL 6). Since RfD_o values differ with respect to the exposure type, additional care should be taken for risk assessment of cadmium depending on the purpose of use. Since exposure to cadmium by groundwater ingestion is covered by TS-266 standards (0.005mg/L) and the SQS for this pathway is calculated based on this criterion, RfD_o value for dietary exposure was used for derivation of the generic SQSs for direct ingestion.

Table 2.30 Equations to Calculate SQSs for Migration to Groundwater Pathway

$$SQS_4 = C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right) \quad (2.20)$$

where;

$\boldsymbol{SQS_4}$ (SQS for migration to groundwater pathway)	-	mg/kg
$\boldsymbol{C_w}$ (target soil leachate concentration)	chemical-specific [a]	mg/L
$\boldsymbol{K_d}$ (soil-water partition coefficient)	chemical-specific [b,c]	L/kg
$\boldsymbol{K_{oc}}$ (soil organic carbon partition coefficient)	chemical-specific [b]	L/kg
$\boldsymbol{f_{oc}}$ (fraction of organic carbon in soil)	0.002 (% 0.2)	g/g
$\boldsymbol{\theta_w}$ (water filled soil porosity)	0.3	cm^3/cm^3
$\boldsymbol{\theta_a}$ (air filled soil porosity)	n-θ_w	cm^3/cm^3
$\boldsymbol{H'}$ (Henry's law constant)	chemical-specific [b.d]	unitless
$\boldsymbol{n}$ (total soil porosity)	1- (ρ_b/ρ_s)	cm^3/cm^3
$\boldsymbol{\rho_b}$ (dry soil bulk density)	1.5	kg/L
$\boldsymbol{\rho_s}$ (soil particle density)	2.65	kg/L

[a] $C_w = DF \times$ (TS-266, WHO or HBL standards) ; [b] See Appendix-E.

[c] For organics $K_d = K_{oc} \times f_{oc}$, for metals K_d value is used.

[d] Assumed to be zero for inorganic contaminants except mercury.

$$HBL^c(mg/L) = \frac{TR \times AT \times 365\, d/yr}{EF \times SF_O \times IF_{w\text{-}adj}} \quad (2.21)^a$$

where;

$\boldsymbol{HBL^c}$ (carcinogenic health based limit)	-	mg/L
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
EF (exposure frequency)	350	day/year
$\boldsymbol{SF_o}$ (oral slope factor)	chemical-specific[b]	$(mg/kg\text{-}day)^{-1}$
$\boldsymbol{IF_{w\text{-}adj}}$(age-adjusted drinking water ingestion rate)	1.086 [c]	L-year/kg-day

[a] This equation is adopted from URL 6. ; [b] See Appendix-E.; [c] See Equation 2.22.

$$IF_{w/adj} = \frac{ED_{1\text{-}6} \times IR_{w/1\text{-}6}}{BW_{1\text{-}6}} + \frac{ED_{7\text{-}31} \times IR_{w/7\text{-}31}}{BW_{7\text{-}31}} \quad (2.22)^a$$

where;

$\boldsymbol{IF_{w/adj}}$ (age-adjusted drinking water ingestion rate)	1.086	L-year/kg-day
$\boldsymbol{IR_{w/1\text{-}6}}$ (drinking water ingestion rate - child)	1	mg/day
$\boldsymbol{IR_{w/7\text{-}31}}$ (drinking water ingestion rate - adult)	2	mg/day
$\boldsymbol{ED_{1\text{-}6}}$ (exposure duration during ages 1-6)	6	year
$\boldsymbol{ED_{7\text{-}31}}$ (exposure duration during ages 7-31)	24	year
$\boldsymbol{BW_{1\text{-}6}}$ (average body weight from ages 1-6)	15	kg
$\boldsymbol{BW_{7\text{-}31}}$ (average body weight from ages 7-31)	70	kg

[a] This equation is adopted from URL 6.

Table 2.30 Equations to Calculate SQSs for Migration to Groundwater Pathway (cont'd)

$$HBL^{nc}(mg/L)=\frac{THQ\times AT\times BW\times 365\,d/yr}{EF\times ED\times \frac{1}{RfD_O}\times IR_W} \quad (2.23)^{a}$$

where;

HBL^{nc} (non-carcinogenic health based limit)	-	mg/L
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30[b]	year
BW (body weight)	70	kg
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfD_o (oral reference dose)	chemical-specific[c]	mg/kg-day
IR_W (drinking water ingestion rate)	2	l/day

[a] This equation is adopted from URL 6.
[b] For non-carcinogens, averaging time equals exposure duration. ; [c] See Appendix-E.

$$DF=1+\frac{Kid}{IL} \quad (2.24)$$

where;

DF (dilution factor)	-	unitless
K (aquifer hydraulic conductivity)	site-specific	m/year
i (hydraulic gradient)	site-specific	m/m
I (infiltration rate)	site-specific	m/year
d (mixing zone depth) [a]	site-specific	m
L (source length parallel to ground water flow)	site-specific	m

[a] See Equation 2.25.

$$d=\left(0.0112L^{2}\right)^{0.5}+d_a\{1-\exp[(-LI)/(Kid_a)]\} \quad (2.25)$$

where;

d (mixing zone depth)	-	m
L (source length parallel to ground water flow)	site-specific	m
I (infiltration rate)	site-specific	m/year
K (aquifer hydraulic conductivity)	site-specific	m/year
d_a (aquifer thickness)	site-specific	m

2.2.5.2 Chromium

Although SQSs for ingestion are more conservative than most of the generic SQSs for inhalation of fugitive particulates, it is not the case for chromium (US EPA, 1996b). Because of the carcinogenicity of hexavalent chromium (Cr^{+6}) through inhalation exposure, SQS calculated for this pathway is lower than the

SQS for ingestion. Therefore, due attention should be paid for estimating site-specific SQSs, especially when site conditions are convenient for significant dust emissions; e.g., dry, dusty soils; high average annual wind speeds; vegetative cover less than 50 percent (US EPA, 1996b).

Since different valences of chromium produce different toxicities (US EPA, 1996b), valent-specific data is recommended to be collected for the sites that are likely to be contaminated with chromium (URL 6). Because of the high carcinogenic potency of Cr^{+6}, chromium (total) is based on the SQSs calculated for Cr^{+6}.

2.2.5.3 Lead

Lead is considered to be a special case chemical by US EPA, because of the difficulty in developing a RfD_o (URL 6). For this reason, a generic soil screening level for lead has not been calculated by US EPA. However, models are recommended in order to assess lead exposure. One of these models is *Integrated Exposure Uptake Biokinetic Model (IEUBK)* which is designed specifically for evaluating lead exposures in children (US EPA, 1994). With use of this model, US EPA (1994) has calculated a SSL of 400 ppm for residential land-use.

Another model developed by US EPA is *Adult Lead Model.* The model is used for assessing risks associated with non-residential adult exposures to lead in soil (US EPA, 1999; US EPA, 2003b). However, these models are based on a different calculation methodology and different toxicity criteria are used for these calculations, such as biokinetic slope factor (in μg/dL per μg/day) (US EPA, 2003b). This model has also been used by the UK DEFRA (2002d) and soil quality standard was determined as 450 mg/kg which is close to the value determined by US EPA.

On the other hand, US EPA (URL 6) recommends 400 mg/kg for residential soils for screening purposes, and proposes 15 μg/L as maximum concentration level in water (US EPA’s action level for water). In this regard, since no toxicity criteria are available for lead, 400 mg/kg is adopted as the generic SQS for ingestion-dermal absorption pathway. For migration to groundwater pathway, the acceptable groundwater concentration given in TS-266 (10 μg/L) is used for calculations of the SQS.

2.2.5.4 Polychlorinated Biphenyls (PCBs)

PCBs refer to a group of chemicals which contain 209 individual compounds (congeners) (URL 8). Most often the trade name, Aroclor, is used to describe PCBs (URL 8). Aroclors are coded with respect to their parent molecule (the first two digits) and their chlorine content by weight (last two digits) (URL 6). For example; the parent molecule for Aroclor 1260 is biphenyl and it contains 60% chlorine.

PCBs are classified among probable human carcinogens (URL 8). Since most toxicity testing has been done on these specific commercial mixtures i.e., Aroclors (URL 8), PCB exposures are often characterized in terms of Aroclors (URL 6) (e.g., in France). However, US EPA founds this approach imprecise and inappropriate (URL 6). Because, once these mixtures are released to environment, they differ in composition due to partitioning, biotransformation, and bioaccumulation (URL 8). Therefore, congener or isomer or total PCBs analyses are recommended by US EPA (URL 6).

In IRIS (URL 7), different toxicological data are proposed with respect to the following groups of PCBs:

- high risk and persistence,
- low risk and persistence, and
- lowest risk and persistence.

IRIS defines Aroclor 1260 as a persistent mixture creating more tumors than less persistent mixture Aroclor 1016 (URL 7). On this account, Aroclor 1016 has been considered to pose low risk, whereas all other Aroclors have been considered to pose high risk toxicity values and appropriate values has been assigned (URL 6). In this respect, generic SQSs were derived based on low risk group PCBs (including only Aroclor 1016 mixtures) and high risk group PCBs (including mixtures other than Aroclor 1016). For this purpose, the corresponding toxicity criteria given in IRIS (URL 7) were used.

As a result, ingestion SQS for high risk group PCBs is found as 0.2 mg/kg, and for low risk group it is found as 1 mg/kg for residential land use. For commercial/industrial land-use outdoor worker, 0.8 mg/kg and 4 mg/kg are found for high risk and low risk group PCBs, respectively (Appendix-D). US EPA (1990) recommends 1 ppm for residential land-use and 10-25 ppm for industrial land-use (regardless of the pathways) as the *soil action levels*. These values are also calculated by US EPA with respect to 10^{-6} risk level. Considering the purpose of use of SQSs and soil action levels of US EPA, SQSs derived are compatible with these values.

2.2.5.5 Dioxins

Dioxins represent a group of chlorinated organic chemicals that have similar structures. Although these chemicals have similar toxicological properties, their degree of toxicity differs (URL 6). In order to adjust the measured concentration to a toxicity equivalent (TEQ) concentration (i.e., to calculate overall toxicity of the dioxin mixture), toxicity equivalence factors (TEFs) are used (URL 6). Dioxin-like TEFs are provided for dioxins, furans and PCBs (URL 6).

The isomer 2,3,7,8 TCDD is defined as the most widely studied compound in this class (US EPA, 2000). This compound represents the reference compound for this class (i.e. TEF = 1.0), thus it is simply called as "dioxin" (US EPA, 2000). Dioxin is often used to refer to the complex mixtures of 2,3,7,8 TCDD and related compounds (US EPA, 2000). Thus, SQSs are calculated for 2,3,7,8 TCDD by using the toxicological data given in RAIS (URL 3). Ingestion SQS is calculated as 0.000004 mg/kg (0.004 ppb) for residential land use and 0.00002 mg/kg (0.02 ppb) for commercial/industrial land use - outdoor worker (see Appendix-D). Whereas, US EPA (1998) recommends *soil action levels* of 1 ppb for residential land-use (which corresponds to 2.5×10^{-4} lifetime cancer risk at residential exposure) and 5-20 ppb for commercial/industrial land-use (5 ppb corresponds to 1.3×10^{-4} lifetime cancer risk at commercial /industrial exposure) regardless of the pathways. Considering the purpose of use of Turkish SQSs (i.e., to screen sites that do not need further assessment) and the target risk level (10^{-6}) used for calculation of ingestion SQSs, the calculated SQSs are found to be compatible with the US EPA's values.

2.3 RESULTS AND DISCUSSION

For development of SQSs, first of all, a comprehensive literature review was conducted. Available documents, reports, regulatory standards and guidelines of the European Countries, the US EPA and Canada were collected and examined to grasp the approaches and the procedures utilized for derivation of human health risk based SQSs. In the case of SQSs, it was also necessary to understand the purpose of use (the role of SQSs within the contaminated sites management system) and implementation of these standards.

Reviewing the SQSs of different countries, the important results can be summarized as follows. All industrialized countries are facing with severe land contamination problems forcing them to configure their SQSs in compliance with the physical, political and economical characteristics of their country (Carlon et al., 2007). The general approach of these countries (mostly EU and North American countries) is to set sustainable standards. Studies show that, although risk based SQSs have already been defined by many countries, the researches in this field continue for updating these values. Although adopting the human health risk based SQSs derived by one of these countries were standing as an alternative to developing national SQSs, differences in SQSs (mentioned in Section 2.1.2.7) designated the significance of the region-specific characteristics and the needs of the country on development of national SQSs.

As a consequence, the experiences and findings of these countries were taken into account. The approaches and procedures of other countries established with expertise have been investigated thoroughly and the key components of the study for derivation of Turkish human health risk based SQSs were determined.

Both in Turkey and in Europe, the common industries that can cause soil contamination and the priority soil contaminants were identified and presented in of Appendix-B, which shows the potentially soil contaminating activities and the primary soil contaminants associated with those activities. This table, as well as the list of chemicals that take place in the regulations of other countries, is then utilized to identify the priority soil contaminants for Turkey.

For derivation of human health risk based SQSs for Turkey, the approach of US EPA, which is based on the same principles as that of the other countries, was adopted as an appropriate way of fulfilling the needs of the regulation.

Consequently, the US EPA’s methodology was implemented, and the approaches of the other countries (especially, the Netherlands, Norway and the UK) were utilized (sometimes as a guide, and sometimes for comparison) for development of Turkish SQSs.

The target risk level (10^{-6}) was identified according to the decision of the MoEF by considering the intended use of Turkish SQSs. The exposure scenarios (i.e. residential scenario, and commercial/industrial scenario for indoor workers and outdoor workers) and the exposure pathways (i.e. soil ingestion-dermal contact, inhalation of fugitive dusts and volatiles, ingestion of groundwater) to be used for development of generic SQSs for Turkey were identified. The exposure parameters and contact rates applicable for these scenarios and pathways were determined. The generic site characteristics for Turkey to be used in calculation of SQSs were derived. The physical-chemical and toxicological data required for calculation of SQSs was identified and the necessary data were compiled in an MS Excel based data library. Finally, Turkish SQSs were calculated for three land-use scenarios (i.e. residential land use, commercial/industrial land use: outdoor worker and commercial/ industrial land use: indoor worker) and four primary exposure pathways (i.e. direct soil ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive particulates and ingestion of groundwater). The example calculations are presented in Appendix-C. The generic SQSs derived are presented in Table D.1, Table D.2, and Table D.3 of Appendix-D for each land use type. The chemical specific information used in calculations; human health benchmark values, physical-chemical properties of chemicals and physical state of organic chemicals at typical soil temperatures are presented in Appendix-E for priority soil contaminants.

2.3.1 The Use of Generic SQSs

The generic SQSs represent the soil concentrations of contaminants which are calculated by assuming the reasonable maximum exposure of human receptors to contaminants in a current or future residential land use. In this respect, the generic SQSs will be used to screen the sites that do not need further attention and to identify the sites that need further investigation (i.e., site-specific risk assessment). In addition to these aims, generic SQSs could also be utilized for determination of the initial clean-up goals when site-specific data are lacking (URL 6).

A systematic approach for management of the contaminated sites was required by the new soil pollution control regulation (MoEF, 2010). In the framework of this contaminated sites management system, generic SQSs take part in the generic risk assessment phase.

Generic risk assessment involves comparison of the potential exposure pathways (defined by the actual CSM) with the generic exposure pathways (defined by the generic CSM). Site concentrations can be compared with the generic SQSs, for which the actual exposure pathways are compatible with the generic exposure pathways. However, surface soil concentrations must be compared with the generic SQSs derived for ingestion-dermal contact and inhalation of fugitive particulates pathways, whereas subsurface soil concentrations must be compared with the generic SQSs derived for inhalation of volatiles and migration to groundwater pathways (US EPA, 1996a).

Sites where the measured surface and subsurface soil concentrations below the generic SQSs can be screened out; that is, such sites are clean and need no further investigation. The generic SQSs for the pathways that are not present at the actual site conditions can be disregarded. On the other hand, the other exposure pathways, which are present at the actual site but not considered in the calculation of generic SQSs should be assessed under site-specific risk assessment phase.

2.3.2 Special Considerations for Generic SQSs

Background Soil Concentrations

While comparing the site concentrations with the generic SQSs, the background soil concentrations should also be considered. US EPA (URL 6) defines two types background concentrations; (i) *natural background concentration* (usually limited to metals), and (ii) *anthropogenic background concentration* (includes both organic and inorganic contaminants).

For some chemicals, the SQSs derived by using risk based approaches may be lower than the background soil concentrations (URL 6). US EPA (URL 6) states that arsenic, aluminum, iron and manganese are among the chemicals for which background soil concentrations may exceed generic SQSs. Therefore, not only the potentially contaminated site, but also its surroundings should be assessed in order to identify the typical background concentrations for the site. If generic SQSs for the metal contaminants are below the background soil concentration, then background soil concentration may be accepted as the soil quality criterion for that chemical (SFT, 1999).

Detection Limit for Chemicals

Similarly, for each substance listed in Appendix-D, technically feasible detection limit should be considered during generic risk assessment studies. If calculated generic SQS is below this detection limit, then soil quality criteria should be adjusted with respect to the detection limit.

Sites with Multiple Contaminants

SQSs are developed based on chemical-specific toxicity criteria to eliminate the sites that do not need further investigation. However, there might be sites that are contaminated with multiple chemicals. In such circumstances, generic risk assessment must be performed for each contaminant found at the site (MoEF, 2010). In other words, the site with multiple contaminants must be assessed with respect to the generic SQSs of each contaminant.

During the assessment, the target organ/system under threat should also be considered. Since different chemicals might affect the same target organ/system, the human health effects of each chemical should be evaluated before screening out any site (URL 6).

Table E.4 of Appendix-E was prepared for this purpose using the RAIS database (URL 3). This table can be used for reviewing the target organ/system of the contaminants at site.

Specific Attention to C_{sat}

As described in Section 2.2.4.2.3, if calculated SQS for a chemical is higher than C_{sat}, then C_{sat} is set as the limiting value for that chemical. If site concentrations exceed C_{sat}, it indicates a potential presence of NAPL in soil, which poses risk to groundwater (US EPA, 1996a). Therefore, in such circumstances, further site assessment is required. However, it should also be noted that free-phase contaminants may also be present at concentrations below C_{sat} if multiple organic contaminants are present at site (US EPA, 1996b).

2.3.3 Comparison of Turkish SQSs with the Soil Criteria of Other Countries

As discussed in Section 2.1.2.7, the approaches used for derivation of SQSs differ from country to country, which results in 10 to 100 folds of differences in SQSs. Since soil quality criteria in these countries are based on different assumptions and different purposes of use, it is very difficult to compare the SQSs of different countries with each other. Because of the reasons for differences that were explained in Section 2.1.2.7, a thorough understanding of the procedure followed for derivation of soil quality criteria is needed to compare soil quality criteria of different countries. Otherwise, the differences in SQSs of different countries can be misinterpreted.

Therefore, in order to compare the developed Turkish SQSs with the soil quality criteria of other countries, the following properties of the soil quality criteria were taken into consideration:

- purpose of use, in other words the role of soil quality criteria in the contaminated sites management system (i.e., screening),
- the exposure scenario used (i, residential land use),
- the potential receptors considered (i.e., human beings),
- the pathways of concern (i.e., ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive dusts, ingestion of groundwater), and
- target risk level (i.e., one in a million, 10^{-6}).

Since US EPA’s calculation procedure was used for derivation of Turkish SQSs, developed Turkish SQSs are compared with the soil screening levels (SSLs) of US EPA. Besides, among the countries reviewed in Section 2.1.2, the soil quality criteria of Norway were found to be comparable with the Turkish SQSs because the soil quality criteria of Norway were also derived with respect to the abovementioned items. Norwegian generic soil criteria also address the intermediate risk level and used for determination of further investigation. The generic soil criteria of Norway are based on the sensitive land use in which ecological receptors are considered as well as human receptors for development of soil criteria. However, human health risk based Norwegian soil quality criteria are presented separately with respect to the pathways considered (SFT, 1999). To sum up the approach of Norway for derivation of soil quality criteria; pathway specific standards are calculated and the values for all pathways are combined by taking the harmonic mean to produce a total human exposure limit. This value is then compared with the ecological risk limit and the lowest of these two values is considered as the soil criterion which is then adjusted with respect to the detection limit and background soil concentrations.

In order to compare Turkish SQSs with the Norwegian soil quality guidelines, the additional pathways (inhalation of indoor volatiles, consumption of vegetables and consumption of fish) were disregarded, while the criteria for soil ingestion and dermal contact pathways (calculated separately) were combined by taking the harmonic mean of the concentrations derived for each pathway (see Equation 2.26).

$$C_{ing+der} = \frac{1}{\frac{1}{C_{ingestion}} + \frac{1}{C_{dermal}}} \qquad (2.26)$$

Pathway-specific soil guideline values of Norway are presented in Table 2.31, together with Turkish SQSs and US EPA's SSLs for a number of metals and organic compounds that are important for soil contamination. Besides, Figure 2.13, Figure 2.14, Figure 2.15, and Figure 2.16 are given for easy comparison of the soil quality criteria.

While comparing Turkish SQSs with the soil guideline values of Norway, it should be considered that Norwegian soil criteria are developed based on 10^{-5} target risk level. Despite the difference in target risk levels, Norwegian soil criteria are compatible with Turkish SQSs for ingestion-dermal contact pathway for some substances, such as cadmium, mercury, PCBs, xylene. On the other hand, for some chemicals, such as arsenic, copper, nickel, benzo(a)pyrene, DDT, lindane, etc. 10 folds of difference is observed, which may be explained by the risk level considered. However, significant differences appear for some other substances, such as ethlybenzene, hexachlorobenzene and 1,1,1-trichloroethane. Similar variations are also observed for other pathways.

Table 2.31 Comparison of Turkish SQSs with the Soil Criteria of Norway and the US EPA (SFT, 1999; US EPA, 2002a)

Compound	**NORWAY (TRL=10^{-5})**					**TURKEY (TRL=10^{-6})**				**US EPA (TRL=10^{-6})**			
	ing	**der**	**ing+der**	**inhd**	**gw (for DF=10)**	**ing+der**	**inhv**	**inhd**	**gw (for DF=1)**	**ing+der**	**inhv**	**inhd**	**gw (for DF=1)**
Arsenic	3.8	59.4	3.5	61	0.06	0.4	-	1,321	0.3 $^{\text{TS-266}}$	0.4	-	770	1 $^{\text{MCL}}$
Cadmium	100	342	77.4	137	4.9	70	-	3,155	0.3 $^{\text{TS-266}}$	70	-	1,800	0.4 $^{\text{MCLG}}$
Copper	50,000	-	50,000	-*	40,800	3,129	-	-	70 $^{\text{TS-266}}$	-	-	-	-
Mercury	47	450	42.6	26,800	15.3	13	2	-	0.04 $^{\text{TS-266}}$	23	10	-	0.1 $^{\text{MCLG}}$
Nickel	500	685	289	293	81.6	1,564	-	21,845	1 $^{\text{TS-266}}$	1,600	-	14,000	7 $^{\text{HBL}}$
Zinc	100,000	-*	100,000	-*	16,300	23,464	-	-	637 $^{\text{HBL}}$	23,000	-	-	620 $^{\text{HBL}}$
Benzene	206	1,220	176.2	31,700	0.08	12	0.5	-	0.0005 $^{\text{TS-266}}$	12	0.8	-	0.002 $^{\text{MCL}}$
Benzo(a)pyrene	0.9	2.1	0.6	2.7	4.3	0.06	-	-	0.01 $^{\text{HBL}}$	0.06	-	-	0.4 $^{\text{MCL}}$
DDT	18.1	-	18.1	171,000	40	2	-	-	0.3 $^{\text{WHO}}$	2	-	-	2 $^{\text{HBL}}$
Ethylbenzene	10,000	24,000	7,059	976,000	38.6	58	2	-	0.3 $^{\text{WHO}}$	7,800	400	-	0.7 $^{\text{MCLG}}$
Hexachlorobenzene	20.6	75.4	16.2	4,880	4.2	0.3	-	-	0.0005 $^{\text{HBL}}$	0.3	1	-	0.1 $^{\text{MCL}}$
Lindane	4.7	-	4.7	634	0.03	0.5	-	-	0.01 $^{\text{WHO}}$	0.4	-	-	0.0005 $^{\text{MCLG}}$
Methylene chloride	813	-	813	-*	0.2	85	5	-	0.005 $^{\text{WHO}}$	85	13	-	0.001 $^{\text{MCL}}$
MTBE	10,000	47,900	8,273	-*	3.3	355	20	-	0.008 $^{\text{HBL}}$	-	-	-	-
PCB (1336-36-3)	0.8	5.8	0.7	83.4	0.7	0.2	-	-	0.005 $^{\text{HBL}}$	-	-	-	-
Pentachlorophenol	51.9	224	42.1	183	0.2	0.9	-	-	0.002 $^{\text{HBL}}$	3	-	-	0.01 $^{\text{MCL}}$
Toluene	22,000	87,900	17,596	976,000	52.3	6,257	818	-	0.5 $^{\text{WHO}}$	16,000	650	-	0.6 $^{\text{MCLG}}$
1,1,1-Tricholoroethane	7,000	33,500	5,790	-*	13.7	156,429	640	-	26 $^{\text{HBL}}$	-	1200	-	0.1 $^{\text{MCLG}}$
Trichloroethylene	2,400	11,500	1,986	-*	4.3	108	1	-	0.007 $^{\text{WHO}}$	2	0.07	-	0.003 $^{\text{MCL}}$
Xylene	18,000	71,900	14,396	976,000	80.6	15,643	258	-	0.5 $^{\text{WHO}}$	160,000	-	-	10 $^{\text{MCLG}}$

* Values greater than 10^6.

ing: soil ingestion, ing+der: ingestion and dermal contact, inhv: inhalation of volatiles, inhd: inhalation of particulates, gw: ingestion of groundwater
TS-266: Standards of Turkish Standardization Institute, WHO: Standards of World Health Organization, HBL: Health Based Limits, MCL: Maximum Contaminant Level, MCLG: Maximum Contaminant Level Goal

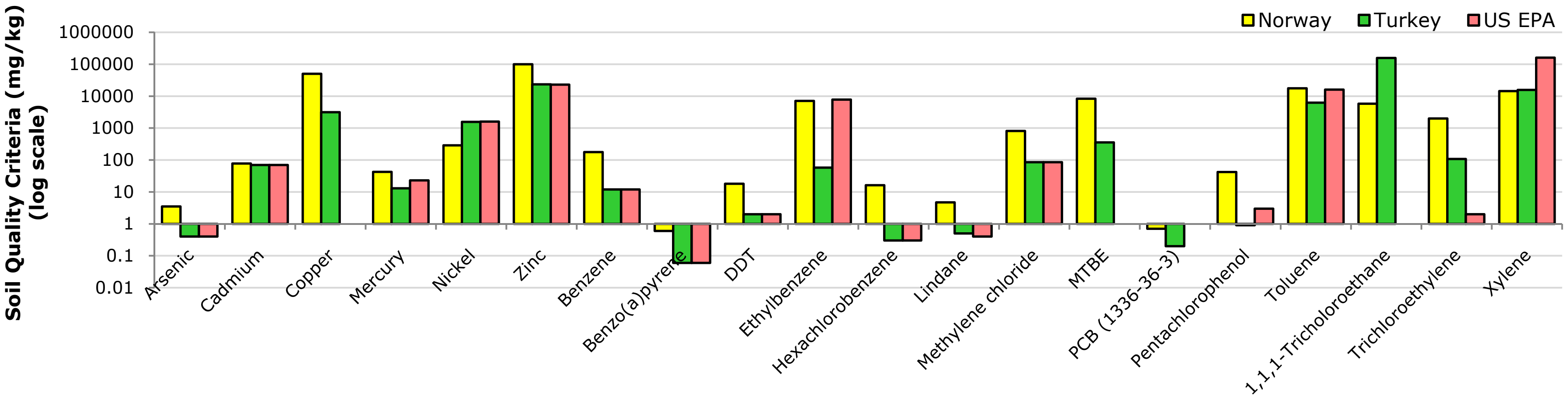


Figure 2.13 Soil Quality Criteria for Ingestion of Soil and Dermal Contact Pathway

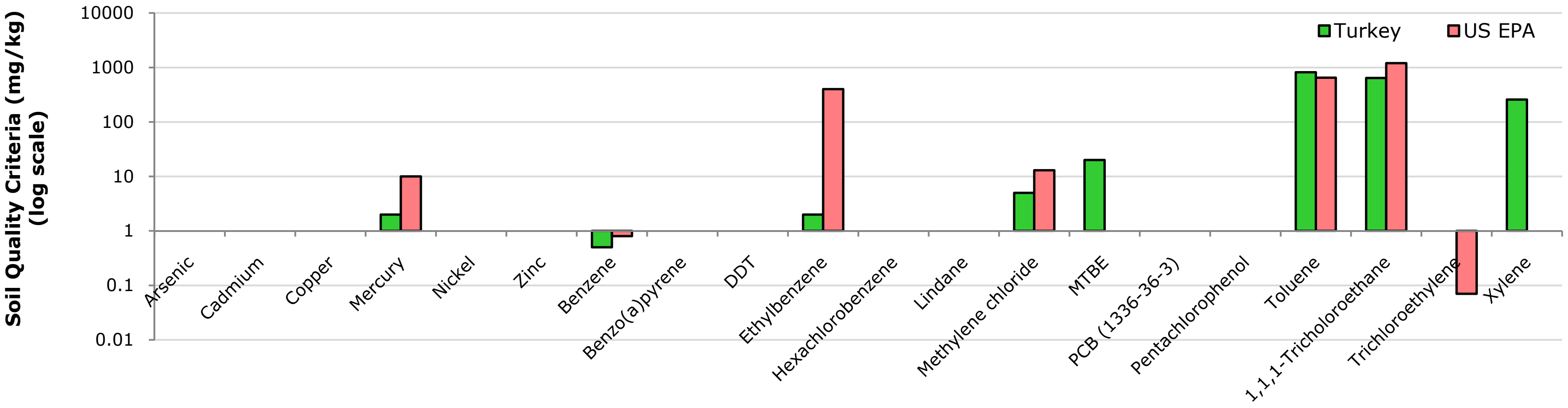


Figure 2.14 Soil Quality Criteria for Inhalation of Volatiles Pathway

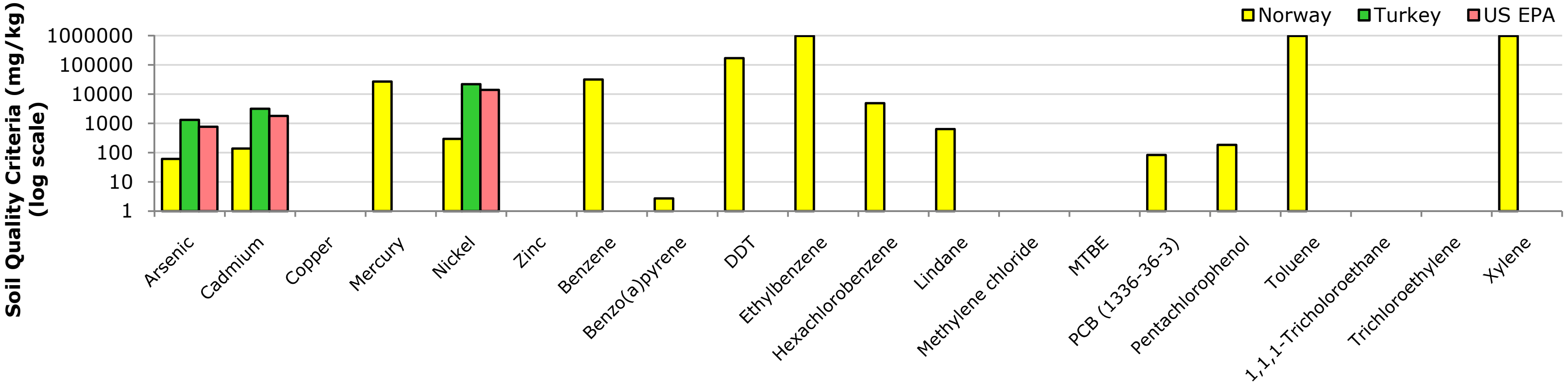


Figure 2.15 Soil Quality Criteria for Inhalation of Fugitive Dusts Pathway

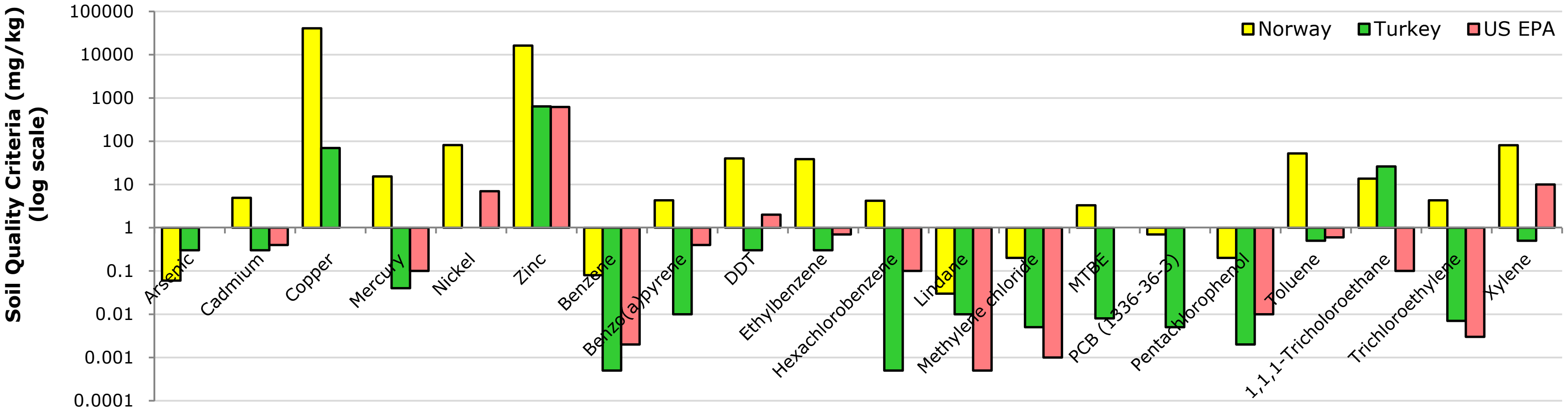


Figure 2.16 Soil Quality Criteria for Ingestion of Groundwater Pathway

A remarkable fact is that, even though Norwegian soil criteria is based on 10^{-5} target risk level and Turkish SQSs are based on 10^{-6} target risk level, Norwegian soil criteria for some substances are lower than Turkish SQSs. The reason for this situation may be described by the use of different physical-chemical and toxicological data. Because Norwegian soil guideline values (SFT, 1999) are derived by use of the physical-chemical and toxicological data available at that time. This difference can also be explained by the differences in approaches, assumptions, parameters and generic site characteristics defined.

As can be seen from Table 2.31, Turkish SQSs are compatible with US EPA's SSLs, since Turkish SQSs were derived by adopting the US EPA's method. Especially, when the ingestion-dermal contact pathway is considered, it can be seen that SQSs derived are close to the standards of US EPA. This is because the exposure parameters and the contact rates, which are the most effective parameters for calculation of SQSs for ingestion-dermal contact pathway, were assumed to be applicable to Turkey. However, up to 10 folds of differences are observed for other pathways, which are due to use of different values for site characteristics, such as air dispersion factor (Q/C), mean annual wind speed (U_m), fraction of vegetative cover (V), soil pH, acceptable groundwater concentration (C_w).

On the contrary, significant differences are observed for some substances, such as ethylbenzene, toluene and xylene, which are due to use of different toxicological data in calculations. It should be mentioned that Turkish SQSs are derived by using the up-to-date toxicological data presented by RAIS (URL 3). However, the soil screening levels of US EPA presented in Table 2.31 has been developed in 2002 and some of the toxicological data are renewed or new toxicological data has been produced since then. For this reason, US EPA recommends its regulatory agencies to calculate site-specific SSLs by use of the up-to-date physical-chemical and toxicological data. For this reason, Turkish SQSs should be updated periodically with use of recent chemical-specific data.

CHAPTER 3

DEVELOPMENT OF AIR DISPERSION FACTORS FOR TURKEY

3.1 THEORETICAL BACKGROUND

SQSs for inhalation of fugitive particulates and volatiles are calculated by use of particulate emission factor (*PEF*) and volatilization factor (*VF*), which represent the inverse of the amount of emissions per volume of air inhaled (m^3/kg). Both of these factors should be derived for generic conditions of Turkey and used to estimate the relationship between soil and air contaminant concentrations resulting from particle suspension or volatilization (US EPA, 2002a). *PEF* refers to the annual average particulate matter emission resulting from wind erosion. As can be seen from the relevant equations presented in Chapter 2 (see Equation 2.14), site characteristics such as fraction of continuous vegetative cover (*V*), mean annual wind speed (U_m), equivalent threshold value of wind speed at 10 m (U_t) and air dispersion factor for fugitive dusts (Q/C_{wind}), which effects the dispersion of fugitive dust emissions in air, are used to calculate *PEF*. Similarly, *VF* refers to the annual average emission resulting from volatilization. *VF* is based on soil characteristics (i.e., f_{oc}, ρ_b, ρ_s, n, θ_w, and θ_a), chemical-specific parameters (K_d, D_i, D_w, and H') and the air dispersion factor for volatiles (Q/C_{vol}), which represents the dispersion of volatile emissions in air (see Equation 2.17 in Chapter 2).

To estimate the emissions of volatiles and dusts and to derive SQSs for inhalation pathway, air dispersion factors, Q/C_{wind} and Q/C_{vol}, are needed. Since these factors depend on the meteorological conditions and site characteristics, factors representing the regional conditions of the country should be used in derivation of SQSs. The dispersion of fugitive dusts and volatiles under the prevailing meteorological conditions can be estimated by use of an air dispersion model simulating the dispersion of pollutants in the atmosphere.

In this regard, one of the specific objectives of this study was to derive the generic air dispersion factors (Q/C_{wind} and Q/C_{vol}) for Turkey and to specify the generic values for the corresponding site characteristics (U_m, U_t, and V) used in derivation of SQSs. For this purpose; the approaches of the countries (mentioned in Section 2.1.2) for derivation of soil quality criteria for inhalation of fugitive dusts and volatiles were reviewed. In some of these countries (e.g. Austria, Canada, Czech Republic, France, Norway, Sweden), inhalation of volatiles at outdoor is not considered among generic pathways and in most of the countries (e.g. Germany, Italy, the Netherlands) a generic value representing the amount of dust emissions per volume of air inhaled (mg/m^3) is given, but the methodology used for derivation of these values is not presented in available documents/reports. On the other hand, the methodology used by US EPA for derivation of air dispersion factors is also utilized by the UK Environment Agency (EA) (2009). However, there exist differences between the approaches used by US EPA and UK EA. The main difference in these approaches is the air dispersion models used for derivation of air dispersion factors. In this chapter, a general overview for the use of air dispersion models in air dispersion factor derivation is presented and the main features of these models used by US EPA and UK EA are summarized (Section 3.1.1). The approaches of these agencies are described and compared (Section 3.1.2). The methodology used for derivation of air dispersion factors for Turkey is explained (Section 3.2), and the results and discussions are presented (Section 3.3).

3.1.1 Use of Air Dispersion Models for Derivation of Air Dispersion Factors

In order to estimate the volatile and dust emissions, air dispersion models stimulating the dispersion of contaminants in the atmosphere are used (US EPA, 1996a). Mathematical formulations, which form the basis of dispersion modeling, are utilized to characterize the atmospheric processes effective in dispersion of pollutants emitted from a source (URL 10). Ambient air concentrations of pollutants at selected receptor locations are estimated by defining the source characteristics, emission rates and meteorological inputs (URL 10).

A simple model called *box model*, which assumes the emissions in a hypothetical box is distributed uniformly throughout the box, was previously used by US EPA for derivation of the *Q/C* factors (US EPA, 1996a). However, box model was not applicable to most site types and meteorological conditions. Thus, box model has been replaced by Industrial Source Complex Model Short-Term Mode, Version 3 (ISCST3) having the following superior characteristics over box model (U.S EPA, 1996a):

- Dispersion modeling from a ground-level area source
- Onsite receptor
- A long-term/annual average exposure point concentration
- Algorithms for calculating the exposure point concentration for area sources of different sizes and shapes.

Likewise, UK EA considers *PEF* and *VF* to estimate ambient volatile and dust emissions. Different from US EPA, UK EA utilized AERMOD (American Meteorological Society/ Environmental Protection Agency Regulatory Model) for derivation of *Q/C* dispersion factor (UK EA, 2009).

These well-known air dispersion models of US EPA, ISCST3 and AERMOD have similar structures as shown in Figure 3.1. However, as described in the following sections, they differ in terms of model basis, features and meteorological input data requirements.

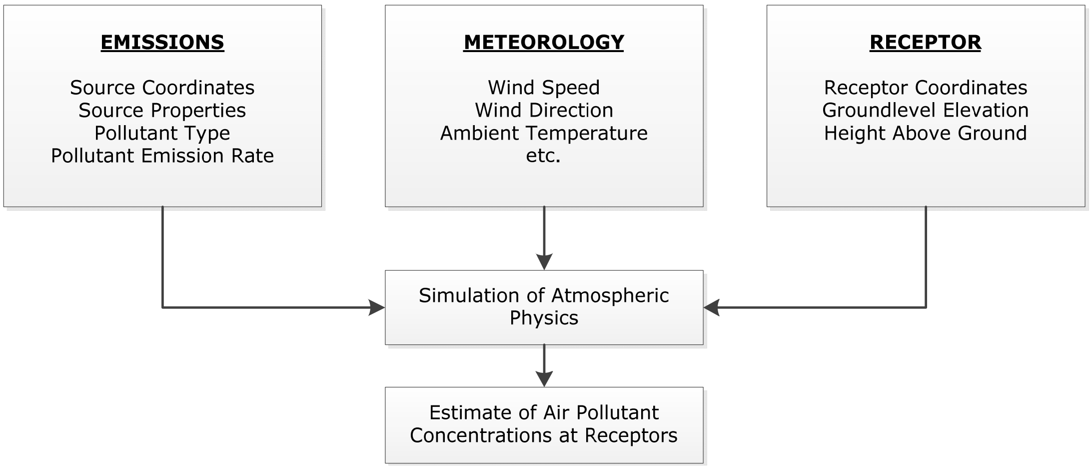


Figure 3.1 General Structure of a Dispersion Model (modified from URL 11)

3.1.1.1 ISCST3 (Industrial Source Complex Short-Term Model,Version 3)

The basis of the ISCST3 model is the steady-state Gaussian plume equation, which is used with some modifications to calculate the dispersion of various air pollutants from several kinds of sources (US EPA, 1995). Emission sources are categorized into four basic types of sources (i.e., point sources, area sources, volume sources, and line sources). An input file stream including the source and receptor characteristics and the meteorological data file are needed to run the ISCST3 model. The run stream setup file contains the modeling options (rural or urban, flat or elevated terrain) and the distribution of the receptors within the area of concern.

The ISCST3 model accepts hourly meteorological data records for wind speed, wind direction, temperature, stability class, urban and rural mixing layer heights for modeling pollutants for no deposition option. ISCST3 uses these data to define the conditions for plume rise, transport and diffusion. The model estimates the concentration value for each source and receptor combination for each hour of input meteorological data (US EPA, 1995).

ISCST3 is a worldwide accepted model for estimating concentrations of air pollutants (US EPA, 1995). However, US EPA promulgated in December, 2006 that ISCST3 is fully replaced by AERMOD (US EPA, 2009).

3.1.1.2 AERMOD (The American Meteorological Society/Environmental Protection Agency Regulatory Model)

AERMOD developed by American Meteorological Society (AMS)/EPA Regulatory Model Improvement Committee (AERMIC) is used as the primary regulatory model in the US (US EPA, 2003c; US EPA, 2009). AERMOD is considered to have a more advanced formulation compared to ISCST3 and provides a more realistic sequence of the diurnal mixing height changes (US EPA, 2003d).

Just as ISCST3, AERMOD can model point, area, volume or line sources (US EPA, 2004b). The run stream setup file of AERMOD is arranged similar to ISCST3. Modeling options, source location and parameter data, receptor locations, meteorological data file specifications and output options are all included in the setup file (US EPA, 2004b).

As an advanced plume model, AERMOD incorporates boundary layer theory, turbulence, dispersion and terrain interactions (URL 9; US EPA, 2003c). Different from ISCST3, AERMOD

- uses non-gaussian probability density function for unstable plume dispersion,
- simulates heat island effects for urban land use,
- requires vertical profiles of meteorological data, and
- requires surface characteristics of surface roughness, albedo, and bowen ratio, which depend on the land use type and influence the turbulence calculations (URL 12).

3.1.2 Approaches used for Development of Air Dispersion Factors

As mentioned before, US EPA and UK EA both rely on the air dispersion factors (*Q/C*) for derivation of *VF* and *PEF* used to calculate the soil quality criteria for inhalation pathway. The approaches of US EPA and UK EA for derivation of *Q/C* dispersion factors are described in Sections 3.1.2.1 and 3.1.2.2, respectively. The comparison of these approaches is also presented in Section 3.2.

3.1.2.1 The Approach of US EPA

ISCST3 model was used by US EPA to develop the dispersion factors used in the Soil Screening Level Guidance (SSLG) (US EPA, 2002a). The SSLG documents were prepared in 1996 and revised in 2002. Because SSLG is not a regulatory requirement, US EPA has not committed resources to update the dispersion factors found in the SSLG (EQM, 2008).

In order to run ISCST3 model, 29 meteorological stations, which are representative of the meteorological conditions across the country, were selected (U.S EPA, 2002a). Dispersion analysis with ISCST3 was performed for a series of square sites with sizes ranging from 0.2ha to 12.1ha (0.5 to 500 acres) (U.S EPA, 2002a). During modeling, volatile and particulate matter contaminants were considered as gaseous pollutants, since the exposure route of concern in both cases was inhalation. Hence, pollutant deposition (e.g., gravity fall out, wet and dry atmospheric scrubbing, down wash, etc.) was not included in the model (EQM, 2008). The model was run by using regulatory default option and assuming flat terrain in rural area (US EPA, 2002a).

Using five years of hourly meteorological data, the maximum annual average air concentrations for 29 sites were estimated (U.S EPA, 2002a). The output concentrations obtained from ISCST3 model is then used to calculate Q/C factors as follows (U.S EPA, 1996a):

$$Q/C = \frac{J_s^{ave}}{\left(C_{air} \times 10^{-9}\, kg/\mu g\right)} \qquad (3.1)$$

where;

Q/C : inverse concentration factor for air dispersion (g/m^2-s per kg/m^3)
J_s^{ave} : average rate of contaminant flux (g/m^2-s)
C_{air} : ISC output maximum air concentration of contaminant (µg/m^3)

If the emission rate (J_s^{ave}) arising from an areal source is assumed to be 1g/m^2-s, then Equation 3.1 simplifies to the inverse of the maximum air concentration of contaminant in kg/m^3 (U.S EPA, 1996a). As the emission rate, J_s^{ave} increases, the maximum air concentration, C_{air} increase at the same rate. Therefore, the ratio of J_s^{ave} to C_{air}, in fact, Q/C does not change.

With this regard, the ambient air concentrations of volatiles and particulate matters for an emission rate of 1 g/m^2-s were estimated. The ambient air concentrations (kg/m^3) predicted by ISCST3 were plotted against different source sizes (acre) (U.S EPA, 1996a). The exponential relation between these parameters was analyzed by CURVEFIT software (US EPA, 2002a), and the best-fit curve equation was generated as

$$Q/C = A \times exp\left[\frac{(ln\, A_{site} - B)^2}{C}\right] \qquad (3.2)$$

where;

Q/C : inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source or at the boundary of the source (g/m^2-s per kg/m^3)
A,B,C : constants based on air dispersion modeling for specific climate zones
A_{site} : areal extent of the site or contamination (acres) *

* Site size can range from 0.5 to 500 acres.

This equation was then provided for estimation of ambient air concentrations of contaminants, as a function of the size of contaminated site (US EPA, 1996a). Each of the 29 sites was subsequently modeled with ISCST3 in the same manner and Q/C factor and A, B, and C constants were produced for each site.

Q/C values obtained for 29 sites were listed in ascending order, in other words inverse of the ambient air concentration values are listed in descending order and 90th percentile value, which corresponds to Los Angeles, California, was set as the most representative Q/C_{vol} to be used for calculating generic SSLs for inhalation of volatiles in the USA (US EPA, 1996a).

However, it was not appropriate to use normalized air concentrations to set a representative Q/C_{wind} factor for calculating the generic SSLs for inhalation of fugitive particulates (US EPA, 1996a). Because, other factors, as well as dispersion, are effective on the amount of particulate emissions, such as mean and threshold wind speeds (U_m and U_t), vegetative cover (V), etc. (US EPA, 1996a). Therefore, Equation 3.3, which is the inverse of PEF equation (Equation 2.14 in Chapter 2), was used to calculate actual concentrations for all sites as

$$C = (C/Q)\left[\frac{0.036(1-V)\times(U_m/U_{t-7})^3\times F(x)}{3600\,s/h}\right] \qquad (3.3)$$

where;

C annual average PM_{10} concentration (kg/m^3)

(C/Q) normalized annual average concentration (kg/m^3 per g/m^2 -s)

V fraction of continuous vegetative cover

U_m mean annual wind speed at 7m (m/s)

U_{t-7} equivalent threshold value of wind speed at 7m (m/s)

$F(x)$ wind speed distribution function from Cowherd et al., 1985.

Actually, this equation is used to estimate particulate emissions caused by wind erosion and it is based on the "unlimited reservoir" model (U.S EPA, 1996a). In this equation V is taken as 0.50, the mean annual wind speed (U_m) for each site was entered and the value of $F(x)$ was estimated from the approach developed by Cowherd et al. (1985). Cowherd et al. (1985) indicated that non-erodible surfaces (e.g., stones, clumps of vegetation), which have high threshold wind speeds for wind erosion, can be simulated by *limited reservoir model.* However, uncovered surfaces with fine material have low threshold wind speeds and can be simulated by *unlimited reservoir model*. The border line between erodible and non-erodible surface particles is determined by the threshold friction velocity of 75 cm/sec. This cutoff value, in turn, corresponds to sandy soil. Surfaces with friction velocities lower than this level tend to generate particulates in suspension (Cowherd et al., 1985).

The threshold friction velocity, which designates the intensity of wind needed to generate particulate suspension, can be determined for any soil aggregate size from of Figure 3.2. Threshold friction velocity is considered as the most effective parameter determining the amount of particulate matter emission (US EPA, 1996a). Hence, US EPA determined a conservative soil aggregate size of 500µm, which corresponds to threshold friction velocity of 0.5 m/s (US EPA, 1996a).

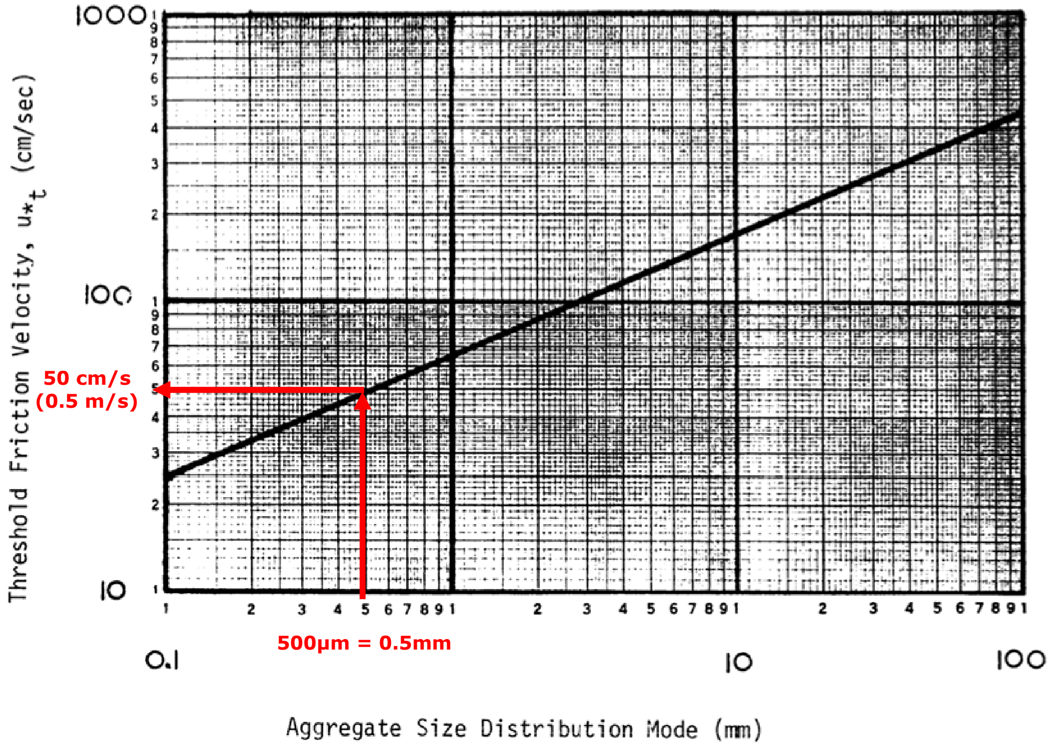


Figure 3.2 Relationship between Threshold Friction Velocity and Aggregate Size Distribution Mode (Cowherd et al., 1985)

In reality, soil also includes non-erodible elements (i.e. soil aggregates larger than 1cm). Because of this reason, threshold friction velocity has to be increased regarding the non-erodible elements. This process is called *correction* of the threshold friction velocity. The quantity of non-erodible elements in soil is designated by the ratio of corrected to uncorrected threshold friction velocity (U.S EPA, 1996a). For example; ratio of 1 accounts for the coal dust on a concrete pad (Cowherd et al., 1985).

In order to determine the appropriate correction factor, US EPA reviewed the wind speed profiles of 29 meteorological stations and determined the typical representative correction factor of as 1.25 (U.S EPA, 1996a). Using this correction factor, the threshold wind speed was determined as 0.625 m/s (0.5m/s x 1.25). Then, equivalent threshold friction velocity at 7 m height was calculated from

$$U_{t\text{-}7}=\frac{U_t}{0.4}\,ln\left[\frac{z}{z_o}\right] \qquad (\ 3.4\ )$$

where;

$U_{t\text{-}7}$ equivalent threshold value of wind speed at 7m (m/s)

z height above surface (700 cm)

z_o surface roughness height, cm (0.5 cm for open terrain)

U_t threshold friction velocity, m/s (0.625 m/s)

Another parameter to be defined at this stage was the surface roughness height, z_o, which is related to obstacles at surface hindering the flow of air (Cowherd et al., 1985). In Figure 3.3, the roughness height scale for various conditions of ground cover is depicted. US EPA (1996a) determined the surface roughness as 0.5 cm considering open terrain conditions. Accordingly, equivalent threshold value of wind speed at 7m ($U_{t\text{-}7}$) was calculated as 11.32m/s.

The final parameter to be entered in the *PEF* equation is *F(x),* where the argument x represents the ratio of threshold friction velocity to mean annual wind speed at 7m. For values of x less than 2, *F(x)* is estimated from the graph given in Figure 3.4 and for values of *x* greater than 2, *F(x)* is approximated by Equation 3.5 (Cowherd et al., 1985):

$$F(x)=0.18\left(8x^3+12x\right).exp\left(-x^2\right) \quad \text{where} \quad x=0.886\frac{U_t}{U_m} \qquad (\ 3.5\ )$$

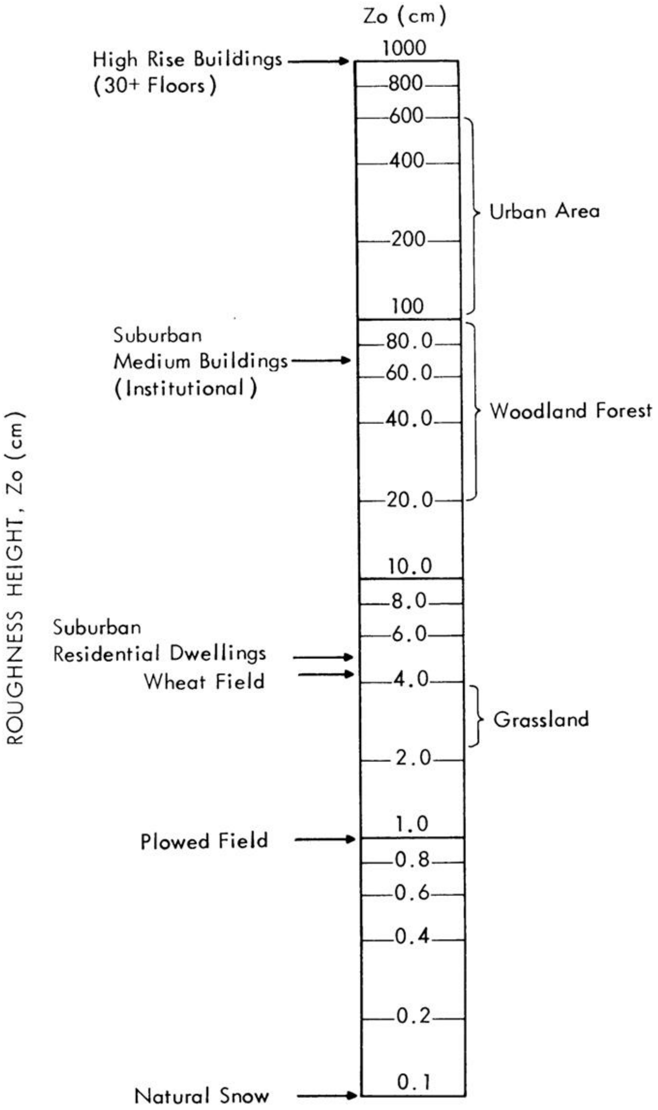


Figure 3.3 Surface Roughness Heights for Various Surfaces (Cowherd et al., 1985)

In the end, annual average particulate emission concentration (see Equation 3.3) for each site was calculated and these values were listed in descending order. The 90th percentile, which corresponds to the *Q/C* value of Minneapolis, Minnesota, was determined as the generic Q/C_{wind} value to be used in derivation of the SSLs for inhalation of fugitive dusts pathway (US EPA, 1996a).

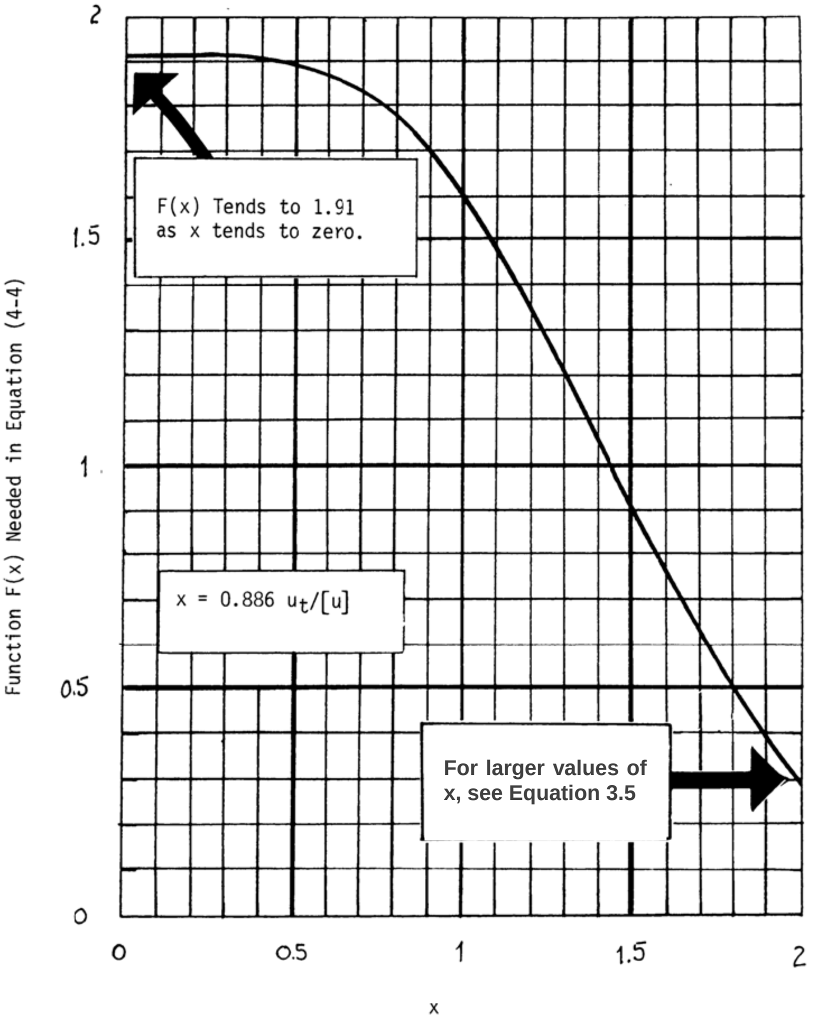


Figure 3.4 Graph of Function *F(x)* used to Estimate Unlimited Erosion (Cowherd et al., 1985)

3.1.2.2 The Approach of UK Environment Agency

A similar approach has been used by UK EA for estimation of dust and volatile concentrations in air, but some modifications has been made in the methodology of the US EPA. The primary difference is the use of AERMOD model for derivation of air dispersion factors, Q/C_{vol} and Q/C_{wind}. The model was run by use of 5 years of hourly meteorological data for 13 cities that are representative of the different climatic conditions in the country (UK EA, 2002). Using AERMOD model, ambient air concentrations for the emission rate of 1 g/m^2.s arising from a square area source with different sizes (ranging from 0.01 ha to 2 ha) were estimated (UK EA, 2002). During this study, two receptor heights, 0.8 m representing child receptor and 1.6 m representing adult receptor, were considered (UK EA, 2002).

Terrain heights were not included in the model. The surface roughness, a parameter needed to run AERMOD model (different from ISCT3 model), was accepted as 0.1 m that is representative of suburban areas (see Figure 3.3). After running the AERMOD model, *Q/C* values were calculated and listed in descending order. The 10th percentile of *Q/C* values (corresponding to 90th percentile of emission concentration) was set as the generic air dispersion factor (*Q/C*) value to be used for deriving soil guideline values both for volatile inhalation and dust inhalation (SGV) (UK EA, 2002). Different from US EPA's approach, air dispersion factor for particulate emissions has not been derived separately. Meaning that, the factors (i.e. U_m, U_t, V) affecting the amount of particulate emissions were not considered in derivation of SGVs for inhalation of fugitive dusts.

PEF was then calculated by use of that single generic *Q/C* value. The annual average wind speed was accepted as 5 m/s considering the wind speed profile all over the country. For the threshold friction velocity, because of the lack of site-specific data, US EPA's conservative value of 0.5 m/s was adopted. This value was then corrected by using the same correction factor of US EPA (1.25) and 0.625 m/s was obtained as the corrected threshold friction velocity. For the surface roughness, 0.1 m, which was also input to AERMOD model, was used. From Equation 3.4, the threshold friction velocity at 10 m was calculated as 7.2m/s. The value of *F(x)* was estimated from Equation 3.5 as 1.22 (UK EA, 2002).

Once the generic values for the parameters constituting the *PEF* was determined, *PEF* was calculated for different land use scenarios by assuming a fraction of vegetative cover of 0.75 for residential scenario, 0.50 for allotment (the small lands allocated for individuals to produce their own food) scenario and 0.80 for commercial scenario (UK EA, 2002).

Since the generic *Q/C* value was determined without including the other parameters forming the *PEF*, this value was also used to calculate volatile emissions. In other words, a single air dispersion factor was used by UK EA for calculation of both *PEF* and *VF*.

3.2 METHODOLOGY FOR DEVELOPMENT OF AIR DISPERSION FACTORS FOR TURKEY

The framework of the study for derivation of generic site characteristics for Turkey was designed as shown in Figure 3.5. The study includes (i) derivation of air dispersion factors and (ii) specification of generic site characteristics such as annual mean wind speed (U_m), equivalent threshold value of wind speed (U_t) and continuous vegetative cover (V). For derivation of air dispersion factors specific to Turkey, the approach to be used was identified by utilizing the approaches of US EPA and UK EA (Section 3.2.1). First of all, the air dispersion model to be used and the meteorological data requirement of the model were identified (Section 3.2.2). The meteorological data obtained from State Department of Meteorology (DMİ) was processed and the meteorological input file was prepared. The air dispersion model was run for defined generic source sizes (Section 3.2.3). The model outputs were evaluated and the generic air dispersion factors were determined with consideration of the specified generic site characteristics (Section 3.2.4). In addition to these studies, the air dispersion model was run once more for varying source sizes, in order to derive air dispersion factors as a function of source sizes (Section 3.2.5), which would be utilized during site-specific risk assessment studies. The details of the study performed are explained in the following sections.

3.2.1 Approach Used for Derivation of Air Dispersion Factors for Turkey

The approaches of US EPA and UK EA are described in Section 3.1.2. In this section, the differences between these approaches are discussed. The advantageous parts of these two approaches were adopted for development of air dispersion factors for Turkey.

The main differences between US EPA and UK EA approaches can be listed as use of different air dispersion model, consideration of different receptor heights, use of different generic source sizes, and use of different methods for determination of generic air dispersion factor for fugitive dust emissions. The differences between these approaches and the approach adopted for derivation of air dispersion factors (Q/C) specific to Turkey are presented in Table 3.1.

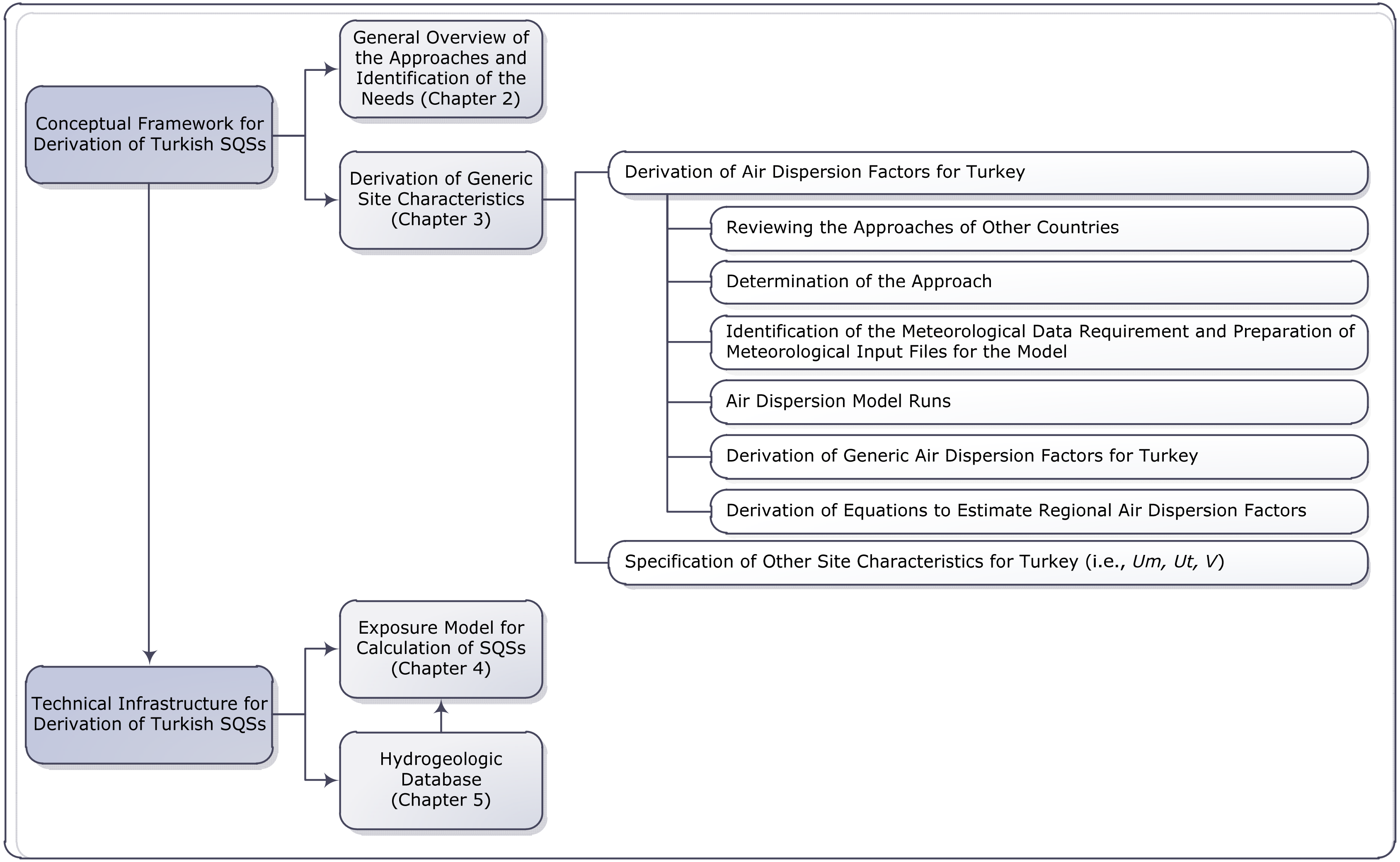


Figure 3.5 Outline of the Study for Development of Air Dispersion Factors for Turkey

Table 3.1 Comparison of the Approaches Used by US EPA and UK EA

	US EPA	**UK EA**	**TURKEY**
Model used	ISCST3	AERMOD	AERMOD
Model run for	29 stations	13 stations	7 stations
Meteorological data used	5 years of hourly data	5 years of hourly data	7 years of hourly data
Receptor height	Ground level	0.8 m and 1.6 m	Ground level
Terrain / Mode	Flat terrain / Rural mode	Flat terrain / Rural mode	Flat terrain / Rural mode
Source sizes modeled to produce site-specific Q/Cs	0.2 ha to 202 ha (0.5 to 500 acre)	-	0.01 ha to 100 ha
Generic source size	0.2ha (0.5 acre) 12.1ha (30 acre)	0.01 ha for residential scenario 0.50 ha for allotment scenario 2.00 ha for commercial scenario	0.01 ha for residential scenario 1.00 ha for commercial/industrial scenario
Mode soil aggregate size	500 µm	500 µm	500 µm
Uncorrected Threshold friction velocity	0.5 m/s	0.5 m/s	0.5 m/s
Correction factor	1.25	1.25	1.25
Corrected threshold friction velocity	0.625 m/s	0.625 m/s	0.625 m/s
Surface roughness height	0.005 m (for open terrain)	0.1 m (for suburban residential setting)	0.05 m (for barren land in suburban residential area)
Fraction of continuous vegetative cover	0.5	0.75 for residential scenario 0.50 for allotment scenario 0.80 for commercial scenario	0.20 both for residential and commercial/ industrial scenario
Mean annual wind speed	4.69 m/s	5.00 m/s	3.00 m/s
Determination of generic Q/C_{vol} value	90th percentile of *Q/C* values (g/m^2-s per kg/m^3) ranked in ascending order	A single generic Q/C value is determined by 90th percentile of *Q/C* values (g/m^2-s per kg/m^3) ranked in ascending order	Maximum of *Q/C* values (g/m^2-s per kg/m^3) ranked in ascending order
Determination of generic Q/C_{wind} value	Q/C value corresponding to 90th percentile of PM_{10} emission fluxes (g/m^2-s) ranked in descending order		Q/C value corresponding to the maximum of PM_{10} emission fluxes (g/m^2-s) ranked in descending order

*US EPA, 2002a; US EPA, 1996a and UK EA, 2002 are utilized to prepare this table.

After reviewing the properties of the air dispersion models used by US EPA and UK EA, it was decided to perform air dispersion modeling studies by use of AERMOD model, which has fully replaced ISCST3 model and is used as the primary regulatory model in the US (US EPA, 2009). It was also decided to run AERMOD model for 7 cities by use of 7 years of hourly meteorological data (the reasons for this selection are explained in Section 3.2.2).

In US EPA and UK EA approaches, different receptor heights were accepted. US EPA considers ground level receptor, whereas UK EA considers two levels of receptors (0.8 m representative of children at 1-6 years old and 1.6 m representative of older children and adults). As emissions from an area source rise up in the air, the concentrations of pollutants decrease due to dispersion and dilution. Because of this reason, ground level receptor assumption gives more conservative (higher air concentration) results. Moreover, in residential land use scenario children playing at ground or in industrial/commercial scenario people working at outside may be exposed to volatile emissions at heights closer to ground level. For this reason, ground level receptor assumption was accepted for derivation of factors for Turkey.

Since the model is not run for a specific region, it is not possible to define terrain heights that apply to the generic scenario. Thus, flat terrain assumption used by both of the agencies was also adopted for Turkey.

US EPA has run ISCST3 model for various source sizes (0.2 ha to 202 ha) to describe the variation of *Q/C* values with respect to different source sizes. This variation was then represented by an equation which is used to estimate site-specific *Q/C* factors for different source sizes. The same approach was also adopted for Turkey and it was decided to run AERMOD model for the source sizes varying from 0.01 ha to 100 ha. On the other hand, US EPA produced generic *Q/C* values for 0.2 ha and 12.1 ha. However, US EPA has used only the *Q/C* value derived for 0.2 ha for calculating soil screening levels (SSLs) for residential and industrial/commercial land use scenarios. On the contrary, UK EA considers for three land use scenarios and defines different source sizes for each scenario (see Table 3.1) which is reasonable. With this regard, a generic source size of 0.01 ha for residential scenario and 1 ha for industrial/commercial scenario were accepted for this study.

As described in Section 3.1.2.1, mode of soil aggregate size, corrected threshold friction velocity, and surface roughness height are the parameters used to estimate derivation of equivalent threshold value of wind speed (U_t), which is used in estimation of particulate emissions caused by wind erosion. For these parameters US EPA defined reasonable conservative values, which were also adopted by UK EA (except surface roughness height). Different from the approaches of US EPA and UK EA, a conservative surface roughness height of 0.05 m, which represents barren land in a suburban residential area (bare rock/sand/clay) (US EPA, 2008), was selected for this study.

For fraction of continuous vegetative cover, US EPA set a generic value of 0.5, whereas UK EA defined different generic values with respect to land use scenarios (see Table 3.1), which are all more than 0.75. As known, vegetative cover is related to the mean annual rainfall observed at a country. For this reason the rainfall distribution in Turkey was considered. As can be seen from Figure 3.6, annual cumulative rainfall in the central parts of the country is less than 500 mm. Whereas, except specific regions (e.g. East and West Black Sea Region, West Mediterranean, and South Aegean), annual cumulative rainfall observed in the rest of the country is less than about 900 mm. In this context, the generic value for the fraction of vegetative cover was determined with respect to the worse scenario, and the rainfall amount, in turn vegetation amount, in the central part of the country was considered. Hence, fraction of continuous vegetative cover was accepted as 0.2 for this study.

One of the main differences between US EPA and UK EA approaches was the methods used for selection of the generic Q/C values. As described in Section 3.1.2.1, US EPA determined two generic Q/C values; Q/C_{vol} to account for volatiles and Q/C_{wind} to account for fugitive dusts. For determination of Q/C_{wind}, US EPA has also considered the effects of other factors (i.e. U_m, U_t, V), which influence the amount of particulate emissions. Whereas, UK EA selected a single Q/C factor to account for both volatiles and fugitive dusts. Since, US EPA mentions about the significance of the other factors on the amount of particulate emissions, US EPA's approach was adopted for this study. The generic value for the mean annual wind speed for Turkey was also identified by use of this approach of US EPA as described in Section 3.1.2.1.

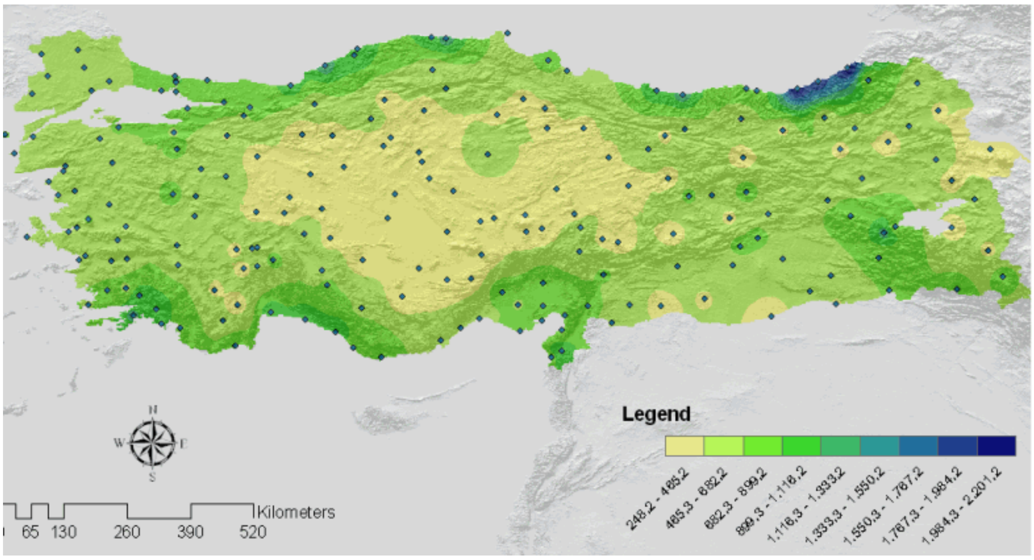


Figure 3.6 Distribution of Annual Cumulative Rainfall in Turkey for 1971-2000 (URL 13)

3.2.2 Meteorological Data Requirement

Meteorological data is one of the primary data type needed to perform air dispersion modeling. In order to run AERMOD, both surface and upper air meteorological (upper air soundings) data are required. However, in Turkey, upper air soundings are available only for 8 meteorological stations, which are operated by the State Department of Meteorology (DMİ). These stations are located in Adana, Ankara, Diyarbakır, Erzurum, Isparta, İstanbul, İzmir, and Samsun. The geographical distribution of these meteorological stations is given in Figure 3.7.

On the other hand, the meteorological station in Erzurum started recording the upper air data in the end of 2006 and data recorded at this station was not sufficient and qualified enough to include in the modeling studies when this study was performed. Because of this reason, Erzurum station was excluded from the study. It was decided to analyze 10 years of meteorological data, in order to assure that worst case conditions are found and identified. However, it was learnt from the DMİ staff that the upper air meteorological data after 2003 are more qualified to perform modeling studies. Therefore, the period was reduced to 7 years (2003 to 2009) and meteorological data for Adana, Ankara, Diyarbakır, Isparta, İstanbul, İzmir, and Samsun meteorological stations were obtained from DMİ.

Figure 3.7 Distribution of the Meteorological Stations Recording Upper Air Data

Since DMİ does not provide processed meteorological data to be entered directly to air dispersion models, the raw data obtained from DMİ needs to be processed by use of the meteorological data preprocessor called AERMET. AERMET (US EPA, 2004c) utilizes two kinds of meteorological data; hourly surface observations and twice-daily upper air soundings (US EPA, 2004c).

The surface and upper air data obtained from DMİ to run AERMET are listed in Table 3.2. Hourly records for temperature, wind speed and direction can be obtained from DMİ, however, for cloud cover and ceiling height data is provided for 7, 14, and 21 hours. Therefore, these data were interpolated to produce hourly data. The upper air soundings (radiosonde data) are used by AERMET to simulate the vertical profiles for temperature and calculate convective mixing heights (US EPA, 2009). In addition to these parameters, surface characteristics, such as surface roughness length, albedo and Bowen ratio, which are effective in turbulence calculations, are needed to run AERMET. Hence, the meteorological input file was prepared by AERMET with the use of a surface roughness height of 0.05 m, albedo of 0.2 and Bowen ratio of 1.5 which correspond to barren land in a suburban residential area (bare rock/sand/clay) (US EPA, 2008).

Table 3.2 Meteorological Data Obtained from DMİ

Surface Observations		**Upper Air Soundings**	
Wind direction	(hourly)	Pressure	(twice-daily)
Wind speed	(hourly)	Height	(twice-daily)
Temperature	(hourly)	Temperature	(twice-daily)
Cloud cover	(07:00 - 14:00 - 21:00)	Relative Humidity	(twice-daily)
Ceiling height	(07:00 - 14:00 - 21:00)	Wind Direction	(twice-daily)
		Wind Speed	(twice-daily)

3.2.3 Air Dispersion Model Runs

The run stream input file was prepared for AERMOD model by assuming flat terrain, rural area, ground level receptor, square source and an emission rate of 1 g/m^2-s. The other modeling options used can be seen in Appendix-F. AERMOD was run by use of 7 years of meteorological data for 7 stations for the generic source sizes of 0.01 ha (residential land use) and 1 ha (industrial/commercial land use). The maximum annual average air concentrations estimated by AERMOD are presented in Table 3.3.

Table 3.3 Annual Average Ambient Air Concentrations Estimated by AERMOD

Station	**Residential Scenario** **Source Area = 0.01ha** **(kg/m^3)**	**Commercial/Industrial Scenario** **Source Area = 1ha** **(kg/m^3)**
Adana	0.0362	0.1116
Ankara	0.0190	0.0547
Diyarbakır	0.0254	0.0800
Isparta	0.0306	0.0944
İstanbul	0.0252	0.0759
İzmir	0.0169	0.0505
Samsun	0.0258	0.0782

As can be seen from Table 3.3, the highest annual average air concentration was obtained for Adana, whereas the lowest was obtained for İzmir. Since no terrain effects were included in the model and the same emission conditions apply for each site, the difference between the air concentrations obtained for these cities can only be explained by the meteorological conditions prevailing at those sites. On the other hand, the air concentrations increase with the increasing source size as expected.

3.2.4 Generic Air Dispersion Factors

Air dispersion factors for each station were calculated by using Equation 3.1 and the *Q/C* values obtained are listed in ascending order as given in Table 3.4.

Table 3.4 Estimated Air Dispersion (*Q/C*) Factors for Turkey

Station	Residential Scenario	Commercial/Industrial Scenario
	Q/C for 0.01ha ($g/m^2.s$ per kg/m^3)	**Q/C for 1ha ($g/m^2.s$ per kg/m^3)**
Adana	27.6091	8.9614
Isparta	32.6371	10.5910
Samsun	38.8048	8.9614
Diyarbakır	39.4166	12.4984
İstanbul	39.6668	13.1839
Ankara	52.7426	18.2849
İzmir	59.2417	19.8059

Since the study was performed only for 7 stations, percentile ranking would not yield sufficiently accurate results in this case. Thus, the minimum *Q/C* value (yielding maximum air concentration), which has been obtained for Adana, was selected as the generic for Q/C_{vol} value to be used for derivation of SQSs for inhalation of volatiles pathway. Hence, 27.61 and 8.96 $g/m^2.s$ per kg/m^3 were determined as the generic Q/C_{vol} values for residential and industrial/commercial scenarios, respectively.

In order to determine a generic value for Q/C_{wind}, US EPA approach (described in Section 3.1.2.1), which accounts for the effects of U_m, U_t, and V, was adopted. In this respect, the actual concentrations at each site were calculated by using Equation 3.3. The values for the parameters affecting the actual air concentration (i.e., V, U_m, U_t, $F(x)$) were determined as described in the following paragraphs.

Because of the low mean annual rainfall, especially in the central part of Turkey, and because the lands allocated for industrial facilities are mostly not suitable for vegetation, a generic value of 0.2 was accepted for fraction of continuous vegetative cover. The mean annual wind speed (U_m) for each station was determined from 30 years meteorological bulletin published by DMİ and presented in Table 3.5. As can be seen from this table, the mean annual wind speeds observed at these stations are between 1.4 m/s and 3 m/s, the lowest wind speed is observed in Adana and the highest is observed in İzmir.

To determine the threshold friction velocity, US EPA's conservative approach, which was also adopted by UK EA, was followed. The mode value of soil aggregate size of 500 μm and the corresponding uncorrected threshold friction velocity of 0.5 m/s were also assumed reasonable independent of the site characteristics. This friction velocity was corrected by a factor of 1.25 which results in a corrected threshold friction velocity of 0.625 m/s. The corrected threshold friction velocity was then converted to the equivalent wind speed at a height of 10 m by using the following equation:

$$U_{t\text{-}10}=\frac{U_t}{0.4}\ ln\left[\frac{z}{z_o}\right] \qquad (3.6)$$

where;

$U_{t\text{-}10}$ equivalent threshold value of wind speed at 10m (m/s)

z height above surface (1000 cm)

z_o surface roughness height, cm (5 cm)

U_t threshold friction velocity, m/s (0.625 m/s)

In this equation, a surface roughness height of 0.05 m, which was also used to run AERMOD model, was accepted. Using the mean annual wind speeds (U_m) and the equivalent threshold value of wind speed at 10 m ($U_{t\text{-}10}$) in Equation 3.5, the values for $F(x)$ were estimated for each station (see Table 3.5). Finally, the annual average PM_{10} concentrations were calculated for each station by use of Equation 3.3 and listed in descending order as shown in Table 3.5.

Table 3.5 Estimated Annual Average PM_{10} Concentrations

Station	Mean Annual Wind Speed, U_m (m/s)	Surface Roughness Height, Z_o (cm)	Threshold Friction Velocity at Surface, U_t (m/s)	Threshold friction velocity at 10m, U_{t-10} (m/s)	*x*	*F(x), x<=2*	*F(x), x>2*	Fraction of Continuous Vegetative Cover, *V*	Q/C for 0.01ha (g/m^2.s per kg/m^3)	Annual Average PM_{10} Concentration for 0.01ha (μg/m^3)	Q/C for 1ha (g/m^2.s per kg/m^3)	Annual Average PM_{10} Concentration for 0.01ha (μg/m^3)
İzmir	3	5	0.625	8.28	2.44	NA	6.67E-02	0.2	59.2417	4.29E-01	19.8059	1.28E+00
Diyarbakır	2.5	5	0.625	8.28	2.93	NA	7.80E-03	0.2	39.4166	4.36E-02	12.4984	1.37E-01
İstanbul	2.5	5	0.625	8.28	2.93	NA	7.80E-03	0.2	39.6668	4.33E-02	13.1839	1.30E-01
Samsun	2.4	5	0.625	8.28	3.06	NA	4.19E-03	0.2	38.8048	2.10E-02	12.7910	6.38E-02
Isparta	1.9	5	0.625	8.28	3.86	NA	3.07E-05	0.2	32.6371	9.11E-05	10.5910	2.81E-04
Ankara	1.9	5	0.625	8.28	3.86	NA	3.07E-05	0.2	52.7426	5.64E-05	18.2849	1.63E-04
Adana	1.4	5	0.625	8.28	5.24	NA	2.62E-10	0.2	27.6091	3.67E-10	8.9614	1.13E-09

As seen in Table 3.5, annual average PM_{10} concentration for 0.01 ha source size is lower than that of 1 ha source size by a factor of 3. In fact, this is an expected situation, because as the source area increases, the surface area of emissions increase which results in increasing ambient air concentrations. Since Q/C values represent the inverse of the air concentrations (kg/m^3) per emission flux (1g/m^2.s), the maximum Q/C value corresponds to maximum air concentration. Since the maximum PM_{10} concentration was obtained for İzmir, the corresponding Q/C values were accepted as the generic Q/C_{wind} values for residential and industrial/commercial land use scenarios. Hence, Q/C_{wind} values for residential scenario and commercial/industrial scenario were determined as 59.24 g/m^2.s per kg/m^3 and 19.81 g/m^2.s per kg/m^3, respectively, and the corresponding *PEFs* were calculated as 2.33×10^9 m^3/kg and 7.80×10^8 m^3/kg, respectively. As seen, the Q/C values obtained for volatiles and fugitive dusts differ. Actually, this table designates the impact of U_m, U_t, V, z_o and $F(x)$ on the amount of PM_{10} concentration.

3.2.5 Air Dispersion Factors as a Function of Source Size

In order to obtain air dispersion factors for each station as a function of source size, which could be utilized for estimation of site-specific SQSs, AERMOD model was run for various source sizes (listed in Table 3.6). The Q/C factors estimated for each station and each source size are shown in Table 3.7.

Table 3.6 Input Source Sizes

Source Size	**Source Area**
10 m x 10 m	0.01 ha
20 m x 20 m	0.04 ha
50 m x 50 m	0.25 ha
100 m x 100 m	1.00 ha
250 m x 250 m	6.25 ha
500 m x 500 m	25 ha
1000 m x 1000 m	100 ha

The Q/C values estimated by AERMOD model were plotted against the source sizes (Figure 3.8). The plot was analyzed by using SigmaPlot software, and the exponential relation proposed by US EPA (2002a) was clearly observed between *Q/C* factor and the source area. Equation 3.2 presented by US EPA (2002a) perfectly fit to model data and A, B, C constants were identified for each station as given in Table 3.8.

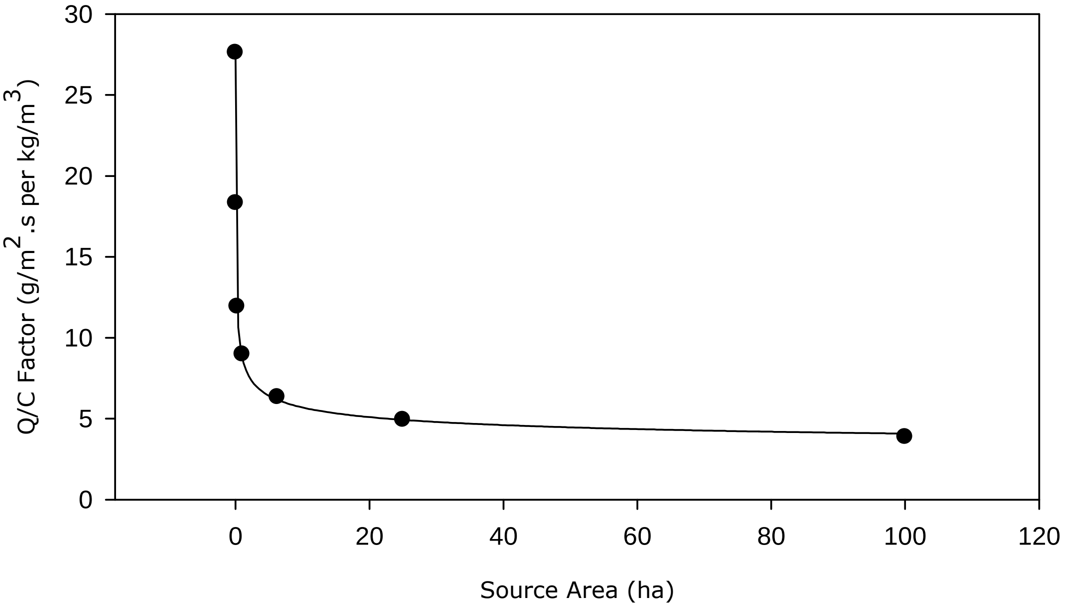


Figure 3.8 Variation of Q/C factor as a Function of Source Area (for Adana)

Table 3.7 Variation of *Q/C* Values with respect to Source Area

Station	Station No	Source Area (ha) 0.01	0.04	0.25	1	6.25	25	100
Adana	17351	27.6091	18.3217	11.9175	8.9614	6.3271	4.9242	3.8551
Ankara	17130	52.7426	35.7526	23.8493	18.2849	13.0770	10.2902	8.1606
Diyarbakır	17281	39.4166	24.9439	16.5317	12.4984	8.8802	6.9440	5.4594
Isparta	17240	32.6371	21.7486	14.0410	10.5910	7.4951	5.8323	4.5727
İstanbul	17062	39.6668	26.5957	17.3883	13.1839	9.3897	7.3481	5.7797
İzmir	17220	59.2417	38.7447	25.8598	19.8059	14.2980	11.2740	8.9254
Samsun	17030	38.8048	25.3872	16.8011	12.7910	9.0926	7.1301	5.6082

Table 3.8 Values for Constants used in Equation 3.2 to Calculate Site-Specific *Q/C* Factors for Various Cities in Turkey

Station	**Station No**	**Constants**		
		A	**B**	**C**
Adana	17351	2.6624	11.4802	110.8763
Ankara	17130	5.5457	11.8718	120.8513
Diyarbakır	17281	4.8166	8.8993	87.1646
Isparta	17240	3.1519	11.4778	110.8781
İstanbul	17062	4.0081	11.5086	113.5284
İzmir	17220	7.4535	9.5692	97.3206
Samsun	17030	4.4160	10.1917	101.1068

3.3 RESULTS AND DISCUSSION

Contaminants released to soil may pose threat on human health through inhalation pathway, as well as other pathways. Contaminants result in air emissions either by volatilization or suspension of contaminants adhered to soil particles depending on the chemical-specific properties. The air concentrations of volatiles and dust particles are estimated by use of *PEF* and *VF*, both of which need to be defined according to site conditions. In order to estimate *PEF* and *VF*, air dispersion factor (*Q/C* factor) is used. Q/C factor designates the inverse of the ratio of contaminant air concentration per unit emission flux and estimated by use of air dispersion models. In this study, the approaches of US EPA and UK EA were reviewed and utilized for estimation Q/C factors specific to Turkey.

Since ISCST3 model has been replaced by AERMOD model in 2006, AERMOD model was used to estimate *Q/C* factors for Turkey. The model was run by using 7 years of hourly meteorological data of 7 stations that are potentially representative of the different climatologic conditions in Turkey.

The outputs of the model were utilized for determination of *Q/C* factors for different meteorological stations (named by the cities where they are located) representing the entire country and for different land use types. The Q/C factors derived for different cities were then analyzed to determine the generic *Q/C* factors to be used for derivation of SQSs for inhalation of volatiles and fugitive dusts. The minimum of the Q/C factors (the maximum annual average air concentration), which is 27.61 g/m^2.s per kg/m^3 for residential scenario and 8.96 g/m^2.s per kg/m^3 for industrial/commercial scenario, were determined as the air dispersion factors for volatiles, Q/C_{vol}.

To determine the generic air dispersion factors for dusts, Q/C_{wind}, actual PM_{10} emissions were calculated by incorporating factors (V, U_m, U_t *and* $F(X)$) affecting wind erosion. The Q/C value corresponding to the maximum PM_{10} emission was selected as the generic Q/C_{wind} values, which are 59.24 g/m^2.s per kg/m^3 for residential scenario and 19.81 g/m^2.s per kg/m^3 for industrial/commercial scenario. By use of these values, the generic PEFs for residential and industrial/commercial scenarios were calculated as 2.33x10^9 m^3/kg and 7.80x10^{8}m^3/kg, respectively.

In addition to the studies described above, AERMOD model was run for various source sizes using the meteorological data of 7 stations to designate the relationship between source size and maximum annual average air concentrations. When the outputs of the model were analyzed, the exponential relation expressed by Equation 3.2 (US EPA, 2002a) was observed. Thus, the model outputs were used to generate the constants of the equation for each meteorological station which would be used in the future for regional scale estimation of air concentrations arising from varying source sizes.

The geographical distribution of these meteorological stations was given in Figure 3.7. Although the meteorological data obtained for these stations represent the different meteorologic conditions observable across Turkey, it would be more representative if more stations could be included in the study. However, upper air soundings (radiosonde data) were available only for 7 stations and the study was limited to those stations. The study could also be performed for other stations producing hourly surface air data by incorporating the upper air meteorological data of the nearest station, but in that case the results obtained would not represent the actual site conditions completely.

In the end of this study, it has been found that the Q/C values obtained for Turkey are lower than the Q/C values of US EPA. Disregarding the prevalent meteorological conditions in the US, this difference can be explained by the use of different air dispersion models. It is known that AERMOD model tends to give higher ambient air concentration results for ground level area sources (Faulkner, 2008) which results in lower Q/C values. On the other hand, although the same air dispersion model was used, the Q/C values obtained for Turkey are also lower than that of UK EA. Other than the difference between meteorological conditions of the countries, the assumptions used in modeling studies caused considerable differences in air concentrations, because AERMOD model is highly sensitive to receptor height and the surface roughness height. As mentioned in Section 3.2, ground level receptor assumption gives higher air concentrations (lower Q/C values) and thus, results in more conservative SQSs. On the other hand, surface roughness height affects vertical profile of wind speed and thus creates considerable differences in air concentrations especially for the ground level sources (US EPA, 2009). Since a more conservative value for surface roughness height was assumed, higher air concentrations were obtained for Turkey.

CHAPTER 4

DEVELOPMENT OF AN EXPOSURE MODEL FOR COMPUTATION OF HUMAN HEALTH RISK BASED SQSs

Derivation of human health risk based SQSs is not a straight forward process and involves use of a large amount of information and data, which are progressively subject to changes or upgrades. SQSs are sensitive to these changes, thus, the derivation process is very dynamic in nature. SQSs are sensitive to changes in

- exposure parameters and contact rates that differ with respect to the exposure scenario considered and the receptors of concern,
- generic site characteristics with respect to soil, hydrogeologic and climatic conditions,
- physical-chemical and toxicological properties of contaminants, which are periodically upgraded or newly produced through recent scientific research.

Therefore, to maintain the sustainability and currency of generic and site-specific SQSs, the improvements in the toxicological and other scientific research should be monitored continuously and SQSs should be upgraded with the use of latest information or data produced.

In order to ensure sustainability, maintenance and dynamism of the developed SQSs, an exposure model was developed, with regard to the adopted approach for derivation of human health risk based SQSs, to facilitate calculation of generic and site-specific SQSs and to eliminate the potential calculation mistakes that may result due to various parameter values and chemical-specific data used in calculations. The model includes the physical-chemical and toxicological data libraries embedded in its structure.

In the following sections, the well-known exposure models and their features are summarized (Section 4.1); the methodology used for development of the exposure model for computation of Turkish SQSs is described and the developed exposure model is introduced (Section 4.2); and finally the result of the study is presented (Section 4.3).

4.1 THEORETICAL BACKGROUND

Exposure models are used for calculation of soil quality criteria and assessment of human health risks resulting from contaminated sites. Some of these models can also be used to make decisions about the need for remediation or to determine remediation goals. Most commonly used exposure models used for these purposes are described briefly in the following sub-sections and related information is summarized and given in Table 4.1.

4.1.1 CSOIL

CSOIL exposure model was developed by the National Institute of Public Health and Environmental Protection (RIVM) of Netherlands in 1994 to determine Dutch Intervention Values (Brand et al., 2000). The model and the dataset were revised in 2001 by RIVM (Brand et al., 2000).

The model has two main functions; "either it can be used to derive human health risk based SQSs, or it can be used to assess human health risks resulting from the contaminated sites" (Brand et al., 2000). Risk assessment function of the model is generally used for deciding on the need for remedial actions (Brand et al., 2000).

4.1.2 RISC HUMAN

RISC-HUMAN (**R**isk **I**dentification of **S**oil **C**ontamination) is an exposure model developed in the Netherlands (in 1995) and used as a tool for "calculation of Dutch intervention values and for determination of site-specific human exposure to contaminants within soil, groundwater and sediment" (Van Hall Instituut, 1998; UK EA, 2003b). The model is based on the CSOIL equations developed by RIVM. However, the additional exposure pathways: "ingestion via contaminated meat and milk, and consumption of groundwater used as drinking water" also take place in the model (Van Hall Instituut, 1998).

RISC-HUMAN is also connected to SEDISOIL and VOLASOIL models developed by RIVM which are used to estimate "exposure via sediments and the indoor air concentration of volatile contaminants", respectively (UK EA, 2003b).

4.1.3 CLEA (Contaminated Land Exposure Assessment)

CLEA model was first developed as a probabilistic model, whereas the latest version of the model serve as a deterministic model for calculation of human health risk based soil quality criteria (UK EA, 2009).

By use of the CLEA model, both generic and site-specific soil quality criteria can be calculated (UK EA, 2009). However, the generic soil quality criteria derived by use of the model cannot be considered as the Soil Guidance Value (SGV), because the assessment criteria published by the UK EA are subject to review by other government departments and agencies (UK EA, 2009).

4.1.4 RISC (Risk-Integrated Software for Clean-ups)

The RISC software was developed by "BP Oil International Ltd based on the American Society for Testing and Materials (ASTM) Risk Based Corrective Action (RBCA) methodology" (UK EA, 2003c). However, additional pathways are also considered within the model.

RISC model can be used for assessment of human exposure to contaminants and calculation of exposure levels through various exposure pathways (UK EA, 2003c). Measured soil, groundwater and air concentrations may be input to software to evaluate potential risks due to contaminated site.

The features of the software are listed as follows (Spence, L.R., 2001):

- calculation of risk levels, clean-up levels or permissible soil concentrations
- conducting probabilistic risk assessment using Monte Carlo analyses
- a stand-alone MS Excel spreadsheet based on the ASTM RBCA algorithms that can be used to calculate initial or Tier 1 risk-based screening levels.

4.1.5 Risk-Based Corrective Action Tool Kit for Chemical Releases

RBCA (Risk-Based Corrective Action) tool kit is designed to calculate risk levels and/or cleanup standards for soil and groundwater (UK EA, 2003a). The model considers the risks posed to human health and environment.

The tool kit follows Tier 1 and Tier 2 calculations defined by ASTM E2081-00 Standard Guide for Risk-Based Corrective Action (UK EA, 2003a). The Tool Kit also includes analytical fate and transport models for air, groundwater and soil exposure pathways (UK EA, 2003a).

4.1.6 Web based Calculator of US EPA

US EPA’s Mid-Atlantic Risk Assessment Website (URL 6) (serving Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia) presents useful information about risk assessment, equations, default screening tables and online calculator to assist Remedial Project Managers, On Scene Coordinators, risk assessors and others involved in decision-making (URL 15).

The online calculator can be used to generate site-specific screening levels or primary remediation goals. The calculator can be used to produce generic screening levels based on land use or to generate site-specific screening levels by changing the exposure parameters (URL 15).

Table 4.1 Fundamental Properties of the Exposure Models

	RISC-HUMAN	**CSOIL**	**CLEA**	**RBCA**	**RISC**	**US EPA Web Based Calculator**
Developed by	Van Hall Instituut in Groningen, Netherlands	RIVM, Netherlands	UK Environmental Agency	RBCA Framework (ASTM), the US	Spence Engineering, USA, and BP Oil International Ltd, UK	US EPA
Toxicological Data	RfD, TCA, TDI Source: RIVM	RfD, TCA, TDI Source: RIVM	Tolerable Daily Intakes (TDIs), Mean Daily Intake (MDIs) and Index Dose (ID)	RfD, SF Source: US EPA IRIS and HEAST	RfD, SF Source: US EPA IRIS, US EPA's National Center for Exposure Assessment (NCEA) and HEAST	RfD, SF Source: US EPA IRIS, US EPA's National Center for Exposure Assessment (NCEA) and HEAST
Target Risk Level	10^{-4}	10^{-4}	-	10^{-6} (cumulative risk =10^{-4})	cumulative risk = 10^{-5}	10^{-6}
Exposure Scenarios	• residential	• residential with garden • places where children play • kitchen, vegetable garden • agricultural use • nature areas • (urban) green areas with nature values • other green areas, infrastructure, buildings and industry	• residential with homegrown produce • residential without homegrown produce • allotments • commercial	• residential (adult and child) • commercial • construction	• residential (adult and child) • recreational (adult and child) • commercial • construction	• residential (adult and child)

Table 4.1 Fundamental Properties of the Exposure Models (cont'd)

	RISC-HUMAN	**CSOIL**	**CLEA**	**RBCA**	**RISC**	**US EPA Web Based Calculator**
Exposure Pathways Considered	• ingestion of soil and dust • consumption of garden vegetables • consumption of drinking water (direct use of groundwater or permeation of plastic pipes) • consumption of fish • consumption of meat • consumption of dairy produce • ingestion of surface water and suspended matter during swimming • inhalation of indoor vapors and dust • inhalation of outdoor vapors and dust • inhalation of vapors while showering • dermal contact with water while showering • dermal contact with soil (outdoors and indoors) • dermal contact with surface water during swimming.	• ingestion of contaminated soil • dermal contact with contaminated soil • inhalation of contaminated soil particles • inhalation of contaminated vapors • consumption of contaminated crops • contact via contaminated drinking water	•direct ingestion of soil and dust • ingestion of soil attached to homegrown produce • consumption of homegrown produce • indoor dermal uptake from soil and dust • outdoor dermal uptake from soil and dust • inhalation of indoor dust • inhalation of outdoor dust • inhalation of indoor vapor • inhalation of outdoor vapor	*Groundwater/surface water exposure:* • ingestion of groundwater • inhalation of groundwater vapor • discharge of contaminated groundwater to surface water • ingestion/dermal contact via swimming • ingestion via fish consumption • aquatic life protection *Surface soil exposure (0 to <1 m):* • inhalation of vapor and particulates • direct dermal contact • ingestion of soil and dust (incidental) • leaching to groundwater *Subsurface soil exposure (>1 m):* • inhalation of vapors • leaching to groundwater	• direct ingestion of contaminated soil • dermal contact with contaminated soil • ingestion of vegetables grown in contaminated soils • ingestion of contaminated groundwater • inhalation of vapors from contaminated groundwater during showering • dermal contact with contaminated groundwater during showering • inhalation of soil vapors in outdoor air • inhalation of soil vapors in indoor air • ingestion of surface water (during swimming) • dermal contact with surface water (swimming) • ingestion of groundwater used for irrigation by children playing under a sprinkler • inhalation of volatile components of groundwater used for irrigation • dermal contact with sprinkler • ingestion of vegetables irrigated with contaminated groundwater.	• ingestion of soil • dermal contact • inhalation of fugitive particulates • inhalation of volatiles • ingestion of groundwater

4.2 METHODOLOGY USED FOR DEVELOPMENT OF EXPOSURE MODEL

The schematical illustration of the methodology used for development of the exposure model for computation of human health risk based SQSs for Turkey is shown in Figure 4.1. The model was developed as a MS Excel based exposure model with several user forms prepared by using Visual Basic Applications (VBA). The model structure was developed as compatible with the adopted approach for derivation human health risk based SQSs. While developing this tool, different exposure models commonly used for assessment of human exposure to soil contaminants (reviewed in Section 4.1) were examined. Some features and interfaces of this model were inspired from these exposure models. Then, the compiled physico-chemical and toxicological data for various chemicals were integrated into the model to allow continuous update of the physico-chemical and toxicological data and subsequent upgrade of the SQSs. Finally, the model was established by integration of necessary algorithms.

4.2.1 Exposure Model: TRSOIL

The developed software was named as TRSOIL, representing the acronym for "Turkish Soil Quality Standards". TRSOIL implements the calculation procedure defined in Section 2.2.4.

The flow chart, which illustrates the relationship of the computational tool with the databases, is shown in Figure 4.2. The main screen of TRSOIL can be seen in Figure 4.3. TRSOIL can be operated either in English or Turkish. By choosing the appropriate language and clicking on the "Continue" button, the user can start up the tool. In every step of the TRSOIL "help menu" is incorporated in order to guide the user for proceeding properly with use of the model.

4.2.1.1 Calculation Steps

By clicking on the "Continue" button in the main screen (Figure 4.3), the model structure, which presents the calculations in stepwise manner together with the available supplementary database management tools, (Figure 4.4) will appear.

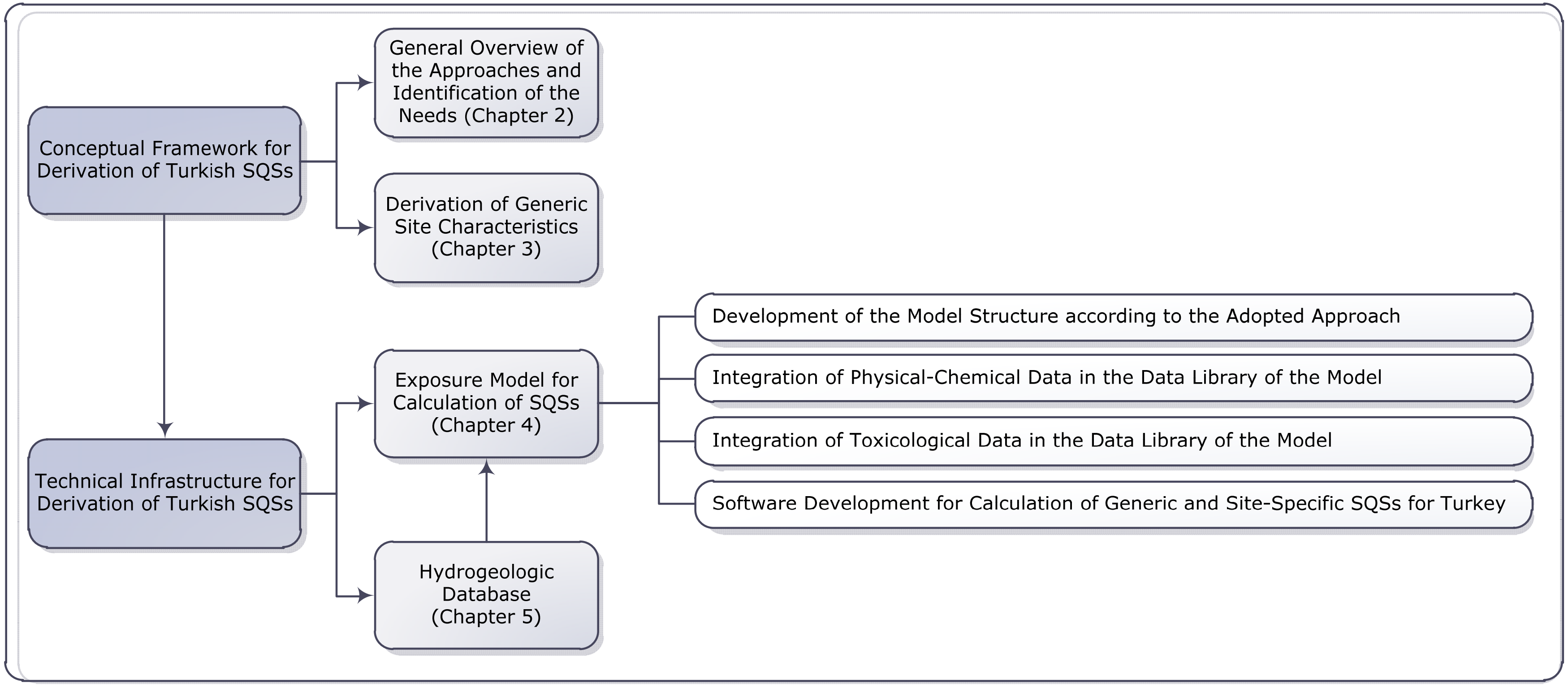


Figure 4.1 Framework for Development of the Exposure Model for Computation of Turkish SQSs

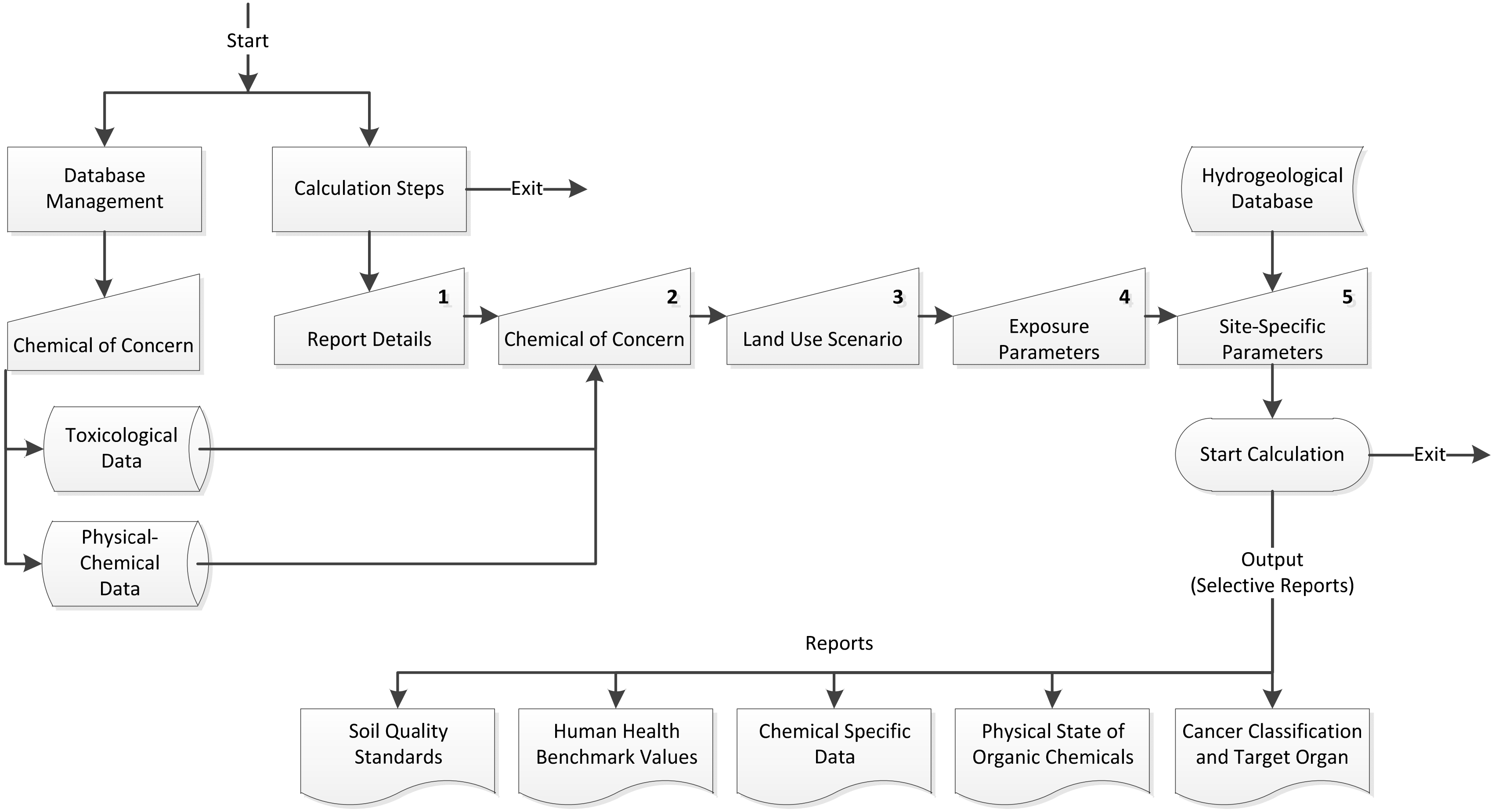


Figure 4.2 Flowchart Illustrating the Operational Structure of TRSOIL

Figure 4.3 The Main Screen of TRSOIL

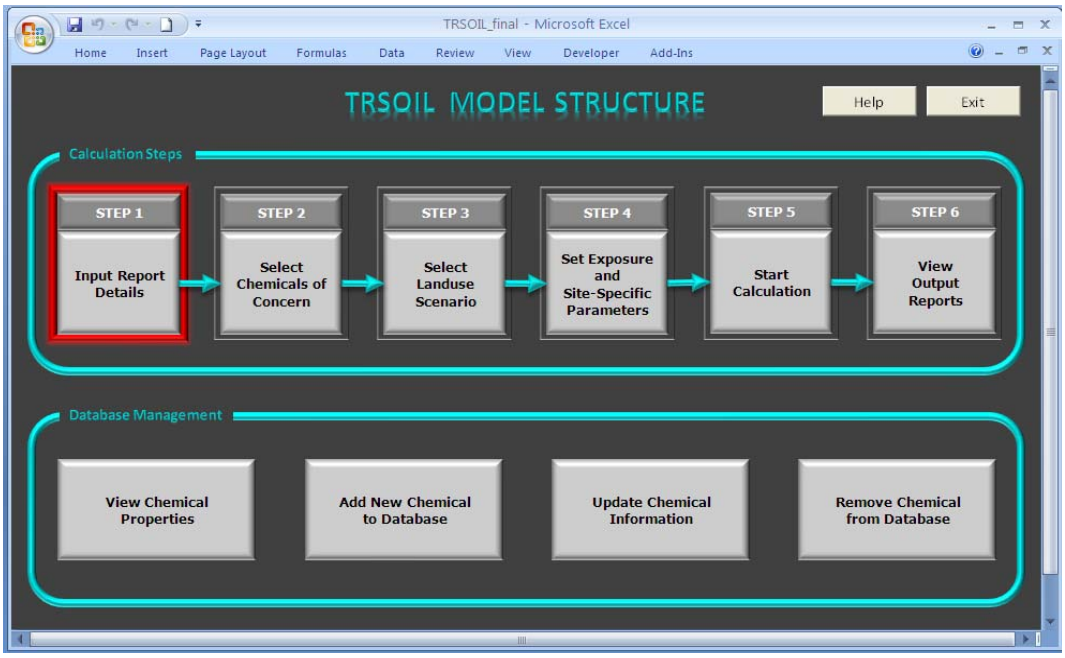


Figure 4.4 TRSOIL Model Structure

TRSOIL model runs following six steps which are presented in "Calculation Steps" frame. These steps are as follows:

Step 1 - Input report details
Step 2 - Select chemical(s) of concern
Step 3 - Select land use scenario
Step 4 - Set exposure and site-specific parameters
Step 5 - Start calculation
Step 6 - View output reports

To calculate soil quality standards these steps should be followed sequentially. The red frame designates the active calculation step.

The first step of calculation is to provide the information desired to be included in the final output report (Figure 4.5). In the final output report, information about the user name, company, report title, job number, date and special notes are entered. This information will appear in the final output report.

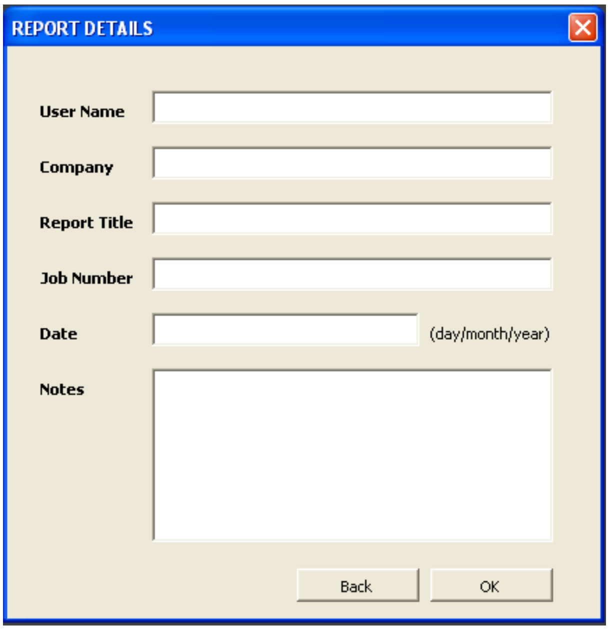
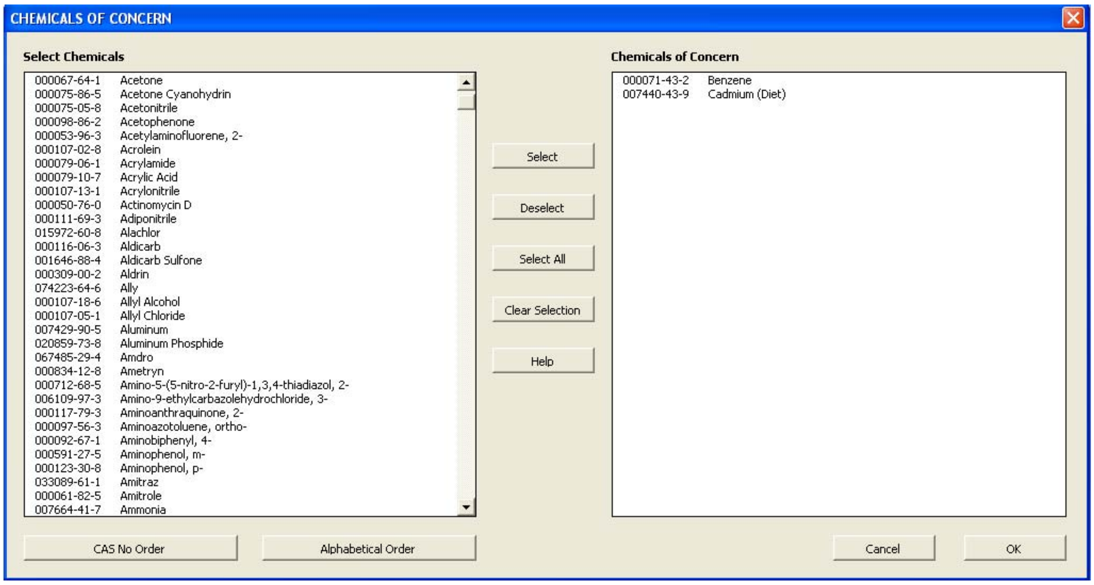


Figure 4.5 Inputting the Report Details

Second step of calculation is selecting the chemicals of concern present at the contaminated site (Figure 4.6) for which soil quality standards will be calculated. Chemicals in the database are listed in this page according to their CAS Numbers and most commonly used names. Chemicals are selected from the list by clicking on the chemical names. Single chemical selection, multiple selection (by use of Ctrl button) or extended selection (by use of Shift button) can be made from the list.



Select Chemicals

000067-64-1	Acetone
000075-86-5	Acetone Cyanohydrin
000075-05-8	Acetonitrile
000098-86-2	Acetophenone
000053-96-3	Acetylaminofluorene, 2-
000107-02-8	Acrolein
000079-06-1	Acrylamide
000079-10-7	Acrylic Acid
000107-13-1	Acrylonitrile
000050-76-0	Actinomycin D
000111-69-3	Adiponitrile
015972-60-8	Alachlor
000116-06-3	Aldicarb
001646-88-4	Aldicarb Sulfone
000309-00-2	Aldrin
074223-64-6	Ally
000107-18-6	Allyl Alcohol
000107-05-1	Allyl Chloride
007429-90-5	Aluminum
020859-73-8	Aluminum Phosphide
067485-29-4	Amdro
000834-12-8	Ametryn
000712-68-5	Amino-5-(5-nitro-2-furyl)-1,3,4-thiadiazol, 2-
006109-97-3	Amino-9-ethylcarbazolehydrochloride, 3-
000117-79-3	Aminoanthraquinone, 2-
000097-56-3	Aminoazotoluene, ortho-
000092-67-1	Aminobiphenyl, 4-
000591-27-5	Aminophenol, m-
000123-30-8	Aminophenol, p-
033089-61-1	Amitraz
000061-82-5	Amitrole
007664-41-7	Ammonia

Chemicals of Concern

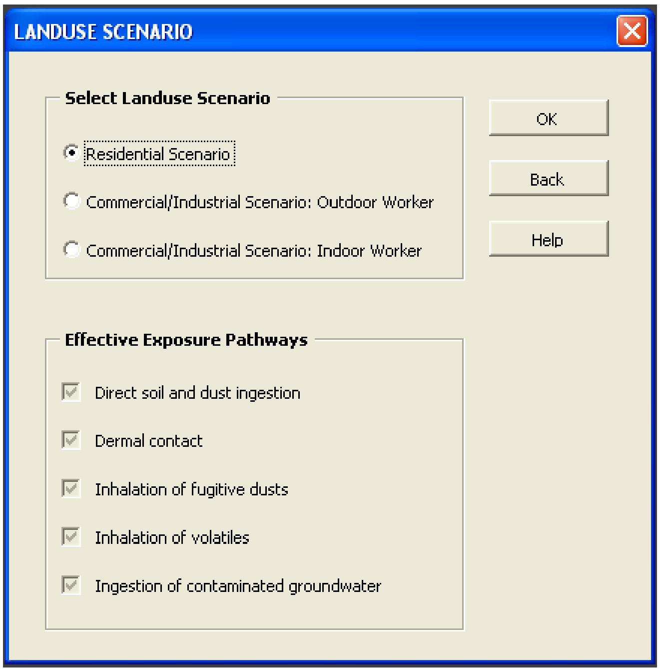
000071-43-2	Benzene
007440-43-9	Cadmium (Diet)

Figure 4.6 Chemicals of Concern

In order to facilitate chemical selection, chemicals are listed in alphabetical order. Chemicals can be listed with respect to their CAS Numbers as well. To list the chemicals in order "CAS No Order" or "Alphabetical Order" buttons can be used. Chemicals are added to the "Chemicals of Concern List" by use of "Select" button. Any chemical in the "Chemicals of Concern List" can be removed by selecting the chemical and clicking "Deselect" button. In order to add all chemicals in the database to "Chemicals of Concern List", "Select All" button is used. Similarly, to clear the list, "Clear Selection" button is used. After selecting the chemicals of concern, the user should click "OK" button.

The third step of TRSOIL is selecting the land use scenario (Figure 4.7). SQSs are calculated for three different land use scenarios. For the same chemical, different soil quality standards are calculated corresponding to each of these land use scenarios due to the differences in exposure assumptions (exposing receptor, exposure duration and frequency, etc.). Therefore, the appropriate land use scenario matching the generic or actual site specific situation should be selected. The land use scenarios are described as follows:

- Residential Scenario: In this scenario, children and adults are considered as the potential receptors and ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive particulates and migration to groundwater are considered as the main exposure pathways.
- Commercial/Industrial Scenario-Outdoor Worker: In this scenario, adults are considered as potential receptors and ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive dusts and migration to groundwater are considered as the main exposure routes.
- Commercial/Industrial Scenario-Indoor Worker: In this scenario, adults are considered as potential receptors, and ingestion and migration to groundwater are considered as the main exposure routes.



Select Landuse Scenario

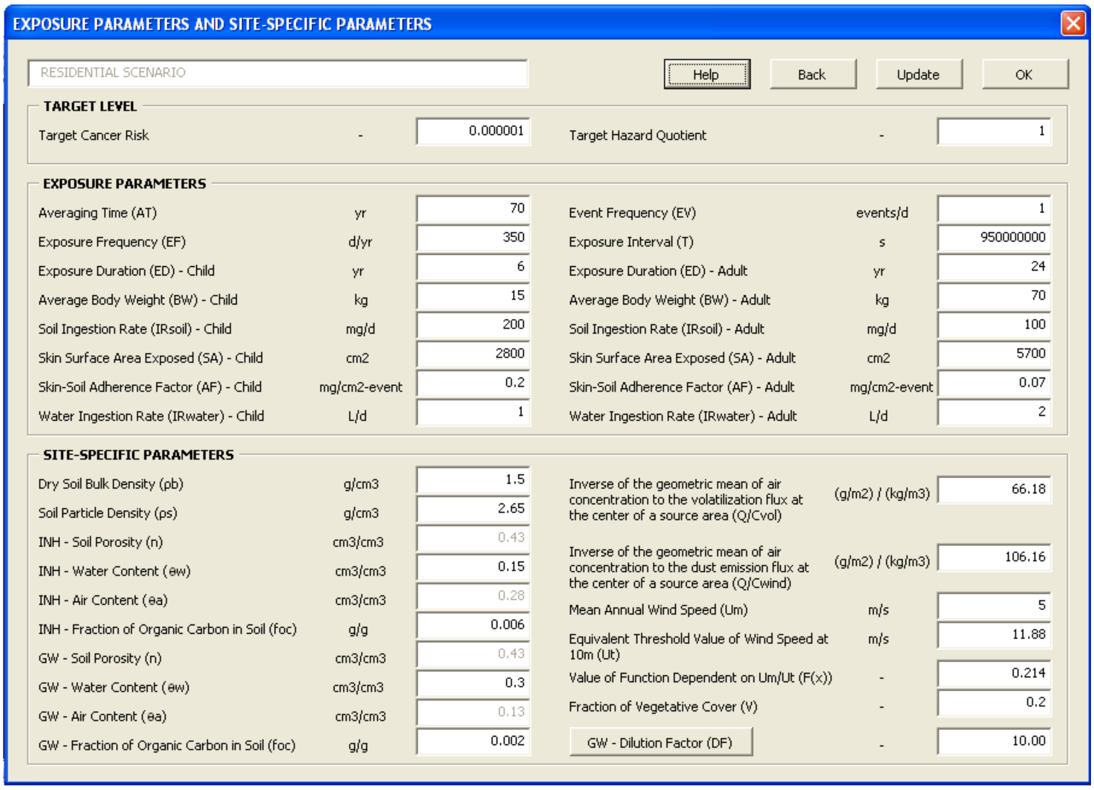
● Residential Scenario
○ Commercial/Industrial Scenario: Outdoor Worker
○ Commercial/Industrial Scenario: Indoor Worker

Effective Exposure Pathways

☑ Direct soil and dust ingestion
☑ Dermal contact
☑ Inhalation of fugitive dusts
☑ Inhalation of volatiles
☑ Ingestion of contaminated groundwater

Figure 4.7 Land Use Selection

In the fourth step, exposure parameters and site-specific parameters used in calculation of SQSs are presented (Figure 4.8). The default values for site-specific parameters for previously selected land use scenario are given in the format of Figure 4.8. These values can be modified according to the actual site conditions. These modifications affect the resulting SQSs directly.



RESIDENTIAL SCENARIO

TARGET LEVEL

Target Cancer Risk	-	0.000001	Target Hazard Quotient	-	1

EXPOSURE PARAMETERS

Averaging Time (AT)	yr	70	Event Frequency (EV)	events/d	1
Exposure Frequency (EF)	d/yr	350	Exposure Interval (T)	s	950000000
Exposure Duration (ED) - Child	yr	6	Exposure Duration (ED) - Adult	yr	24
Average Body Weight (BW) - Child	kg	15	Average Body Weight (BW) - Adult	kg	70
Soil Ingestion Rate (IRsoil) - Child	mg/d	200	Soil Ingestion Rate (IRsoil) - Adult	mg/d	100
Skin Surface Area Exposed (SA) - Child	cm2	2800	Skin Surface Area Exposed (SA) - Adult	cm2	5700
Skin-Soil Adherence Factor (AF) - Child	mg/cm2-event	0.2	Skin-Soil Adherence Factor (AF) - Adult	mg/cm2-event	0.07
Water Ingestion Rate (IRwater) - Child	L/d	1	Water Ingestion Rate (IRwater) - Adult	L/d	2

SITE-SPECIFIC PARAMETERS

Dry Soil Bulk Density (ρb)	g/cm3	1.5
Soil Particle Density (ρs)	g/cm3	2.65
INH - Soil Porosity (n)	cm3/cm3	0.43
INH - Water Content (θw)	cm3/cm3	0.15
INH - Air Content (θa)	cm3/cm3	0.28
INH - Fraction of Organic Carbon in Soil (foc)	g/g	0.006
GW - Soil Porosity (n)	cm3/cm3	0.43
GW - Water Content (θw)	cm3/cm3	0.3
GW - Air Content (θa)	cm3/cm3	0.13
GW - Fraction of Organic Carbon in Soil (foc)	g/g	0.002

Inverse of the geometric mean of air concentration to the volatilization flux at the center of a source area (Q/Cvol)	(g/m2) / (kg/m3)	66.18
Inverse of the geometric mean of air concentration to the dust emission flux at the center of a source area (Q/Cwind)	(g/m2) / (kg/m3)	106.16
Mean Annual Wind Speed (Um)	m/s	5
Equivalent Threshold Value of Wind Speed at 10m (Ut)	m/s	11.88
Value of Function Dependent on Um/Ut (F(x))	-	0.214
Fraction of Vegetative Cover (V)	-	0.2
GW - Dilution Factor (DF)	-	10.00

Figure 4.8 Setting Exposure and Site-Specific Parameters

The actual site-specific dilution factor (*DF*) can also be calculated by using the "GW - Dilution Factor (*DF*)" placed in the right bottom corner. When the "GW - Dilution Factor (*DF*)" button is clicked, a new page will appear asking for the relevant data entry allowing for the calculation of the actual site-specific *DF* (Figure 4.9). In order to calculate the actual site-specific mixing zone depth (*d*) and DF, values for aquifer hydraulic conductivity (*K*), hydraulic gradient (*i*), infiltration rate (*I*), aquifer thickness (d_a) and source length parallel to groundwater flow (*L*) are entered; and then "Calculate" button is clicked. The developed hydrogeological database (described in Chapter 5) will serve for obtaining such aquifer data in the future.

To update and replace the calculated new DF value, "OK" button is clicked. To proceed with the default *DF* (*DF*=10) value, "Back" button is clicked. Similarly, to proceed with the default exposure and generic site-specific values, "OK" button is clicked. If any modification is made, "Update" button is clicked.

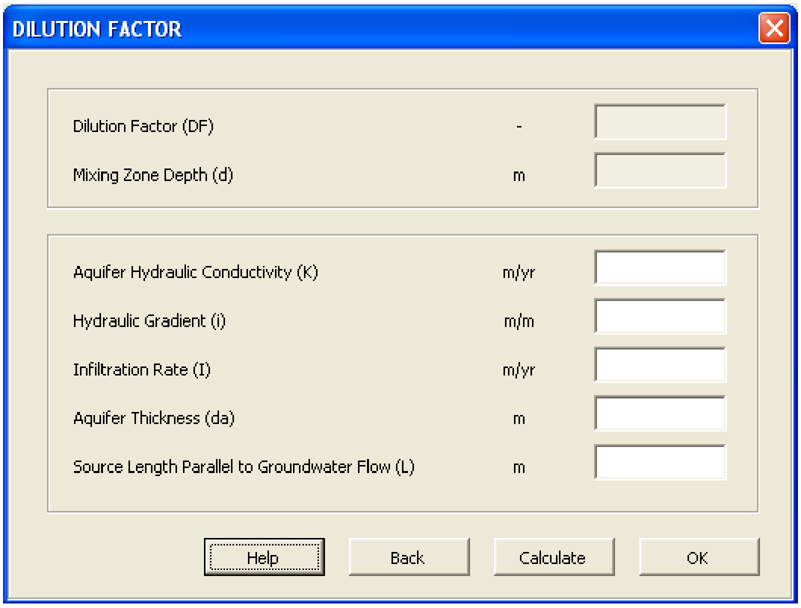


Figure 4.9 Calculating Actual Site-Specific Dilution Factor

Fifth step is starting the SQS calculation process for the selected contaminants and land use scenario. This process takes a few minutes. When calculation is completed, output reports can be viewed (step six). The SQSs, exposure and site-specific parameters, human health benchmarks, chemical specific properties, physical state of organic chemicals, cancer classification and target organ/system can be viewed, printed and saved as outputs of the software (Figure 4.10).

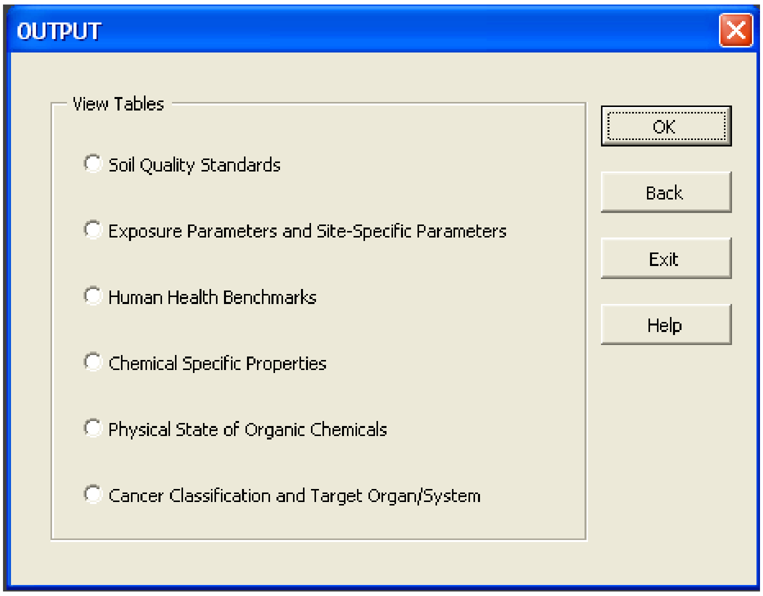
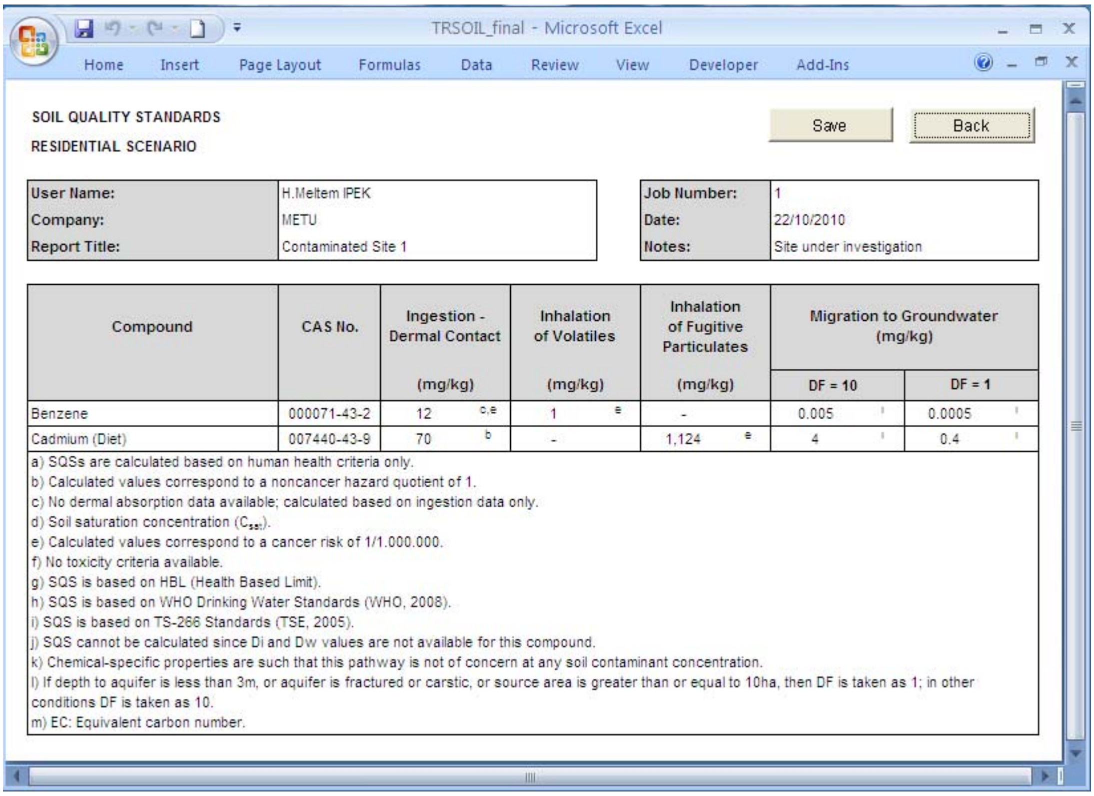


Figure 4.10 Output Selection

Output pages can be viewed by making the following selections:

1) *Generic SQSs:* Calculated pathway specific SQSs can be viewed and saved (Figure 4.11).



SOIL QUALITY STANDARDS
RESIDENTIAL SCENARIO

User Name:	H.Meltem IPEK	**Job Number:**	1
Company:	METU	**Date:**	22/10/2010
Report Title:	Contaminated Site 1	**Notes:**	Site under investigation

Compound	CAS No.	Ingestion - Dermal Contact (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Groundwater (mg/kg)	
					DF = 10	DF = 1
Benzene	000071-43-2	12 [c,e]	1 [e]	-	0.005 [l]	0.0005 [l]
Cadmium (Diet)	007440-43-9	70 [b]	-	1,124 [e]	4 [l]	0.4 [l]

a) SQSs are calculated based on human health criteria only.
b) Calculated values correspond to a noncancer hazard quotient of 1.
c) No dermal absorption data available; calculated based on ingestion data only.
d) Soil saturation concentration (C_{sat}).
e) Calculated values correspond to a cancer risk of 1/1.000.000.
f) No toxicity criteria available.
g) SQS is based on HBL (Health Based Limit).
h) SQS is based on WHO Drinking Water Standards (WHO, 2008).
i) SQS is based on TS-266 Standards (TSE, 2005).
j) SQS cannot be calculated since Di and Dw values are not available for this compound.
k) Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration.
l) If depth to aquifer is less than 3m, or aquifer is fractured or carstic, or source area is greater than or equal to 10ha, then DF is taken as 1; in other conditions DF is taken as 10.
m) EC: Equivalent carbon number.

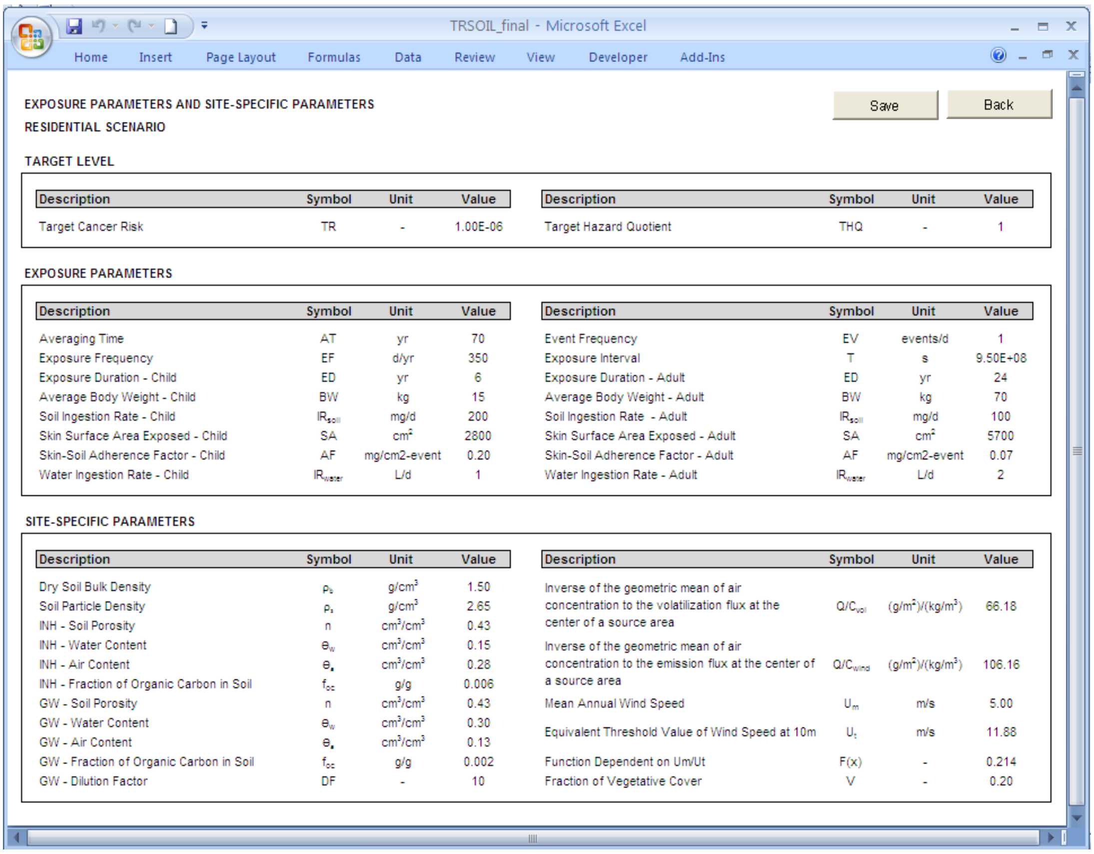
Figure 4.11 Output Screen for SQSs

2) *Exposure Parameters and Site-Specific Parameters:* Exposure parameters and site-specific parameters used in calculation of SQSs can be viewed and saved as an output (Figure 4.12).

3) *Human Health Benchmarks*: Human health benchmark values used in calculations can be viewed and saved as an output (Figure 4.13).

4) *Chemical Specific Properties:* Chemical data used in calculations can be viewed and saved as an output (Figure 4.14).

5) Physical State of Organic Chemicals: Physical state of organic chemicals at typical soil temperature (accepted as 25 °C) can be viewed and saved as an output (Figure 4.15).



EXPOSURE PARAMETERS AND SITE-SPECIFIC PARAMETERS
RESIDENTIAL SCENARIO

TARGET LEVEL

Description	Symbol	Unit	Value
Target Cancer Risk	TR	-	1.00E-06

Description	Symbol	Unit	Value
Target Hazard Quotient	THQ	-	1

EXPOSURE PARAMETERS

Description	Symbol	Unit	Value
Averaging Time	AT	yr	70
Exposure Frequency	EF	d/yr	350
Exposure Duration - Child	ED	yr	6
Average Body Weight - Child	BW	kg	15
Soil Ingestion Rate - Child	IR_{soil}	mg/d	200
Skin Surface Area Exposed - Child	SA	cm^2	2800
Skin-Soil Adherence Factor - Child	AF	mg/cm2-event	0.20
Water Ingestion Rate - Child	IR_{water}	L/d	1

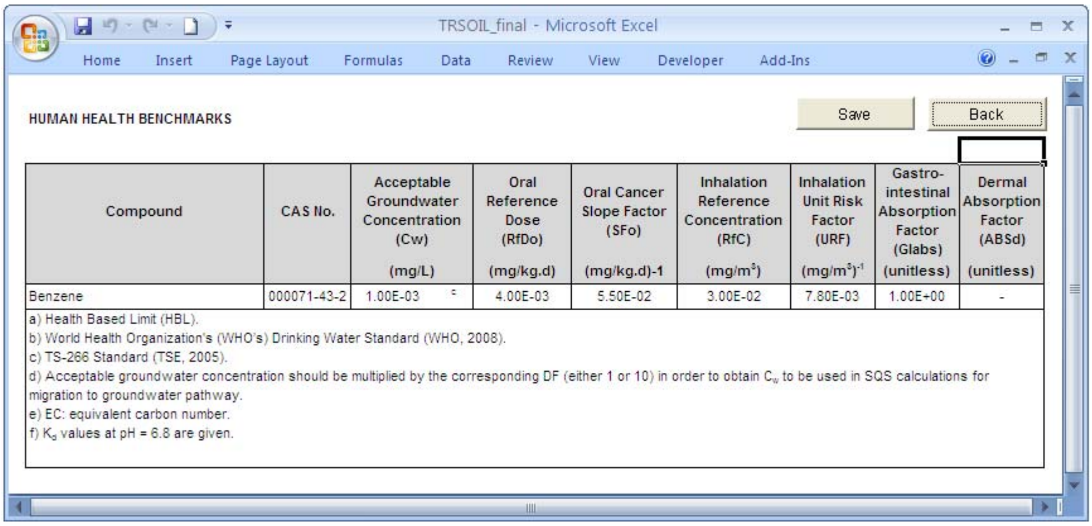
Description	Symbol	Unit	Value
Event Frequency	EV	events/d	1
Exposure Interval	T	s	9.50E+08
Exposure Duration - Adult	ED	yr	24
Average Body Weight - Adult	BW	kg	70
Soil Ingestion Rate - Adult	IR_{soil}	mg/d	100
Skin Surface Area Exposed - Adult	SA	cm^2	5700
Skin-Soil Adherence Factor - Adult	AF	mg/cm2-event	0.07
Water Ingestion Rate - Adult	IR_{water}	L/d	2

SITE-SPECIFIC PARAMETERS

Description	Symbol	Unit	Value
Dry Soil Bulk Density	ρ_b	g/cm^3	1.50
Soil Particle Density	ρ_s	g/cm^3	2.65
INH - Soil Porosity	n	cm^3/cm^3	0.43
INH - Water Content	θ_w	cm^3/cm^3	0.15
INH - Air Content	θ_a	cm^3/cm^3	0.28
INH - Fraction of Organic Carbon in Soil	f_{oc}	g/g	0.006
GW - Soil Porosity	n	cm^3/cm^3	0.43
GW - Water Content	θ_w	cm^3/cm^3	0.30
GW - Air Content	θ_a	cm^3/cm^3	0.13
GW - Fraction of Organic Carbon in Soil	f_{oc}	g/g	0.002
GW - Dilution Factor	DF	-	10

Description	Symbol	Unit	Value
Inverse of the geometric mean of air concentration to the volatilization flux at the center of a source area	Q/C_{vol}	(g/m^2)/(kg/m^3)	66.18
Inverse of the geometric mean of air concentration to the emission flux at the center of a source area	Q/C_{wind}	(g/m^2)/(kg/m^3)	106.16
Mean Annual Wind Speed	U_m	m/s	5.00
Equivalent Threshold Value of Wind Speed at 10m	U_t	m/s	11.88
Function Dependent on Um/Ut	F(x)	-	0.214
Fraction of Vegetative Cover	V	-	0.20

Figure 4.12 Output Screen for Exposure and Site-Specific Parameters



HUMAN HEALTH BENCHMARKS

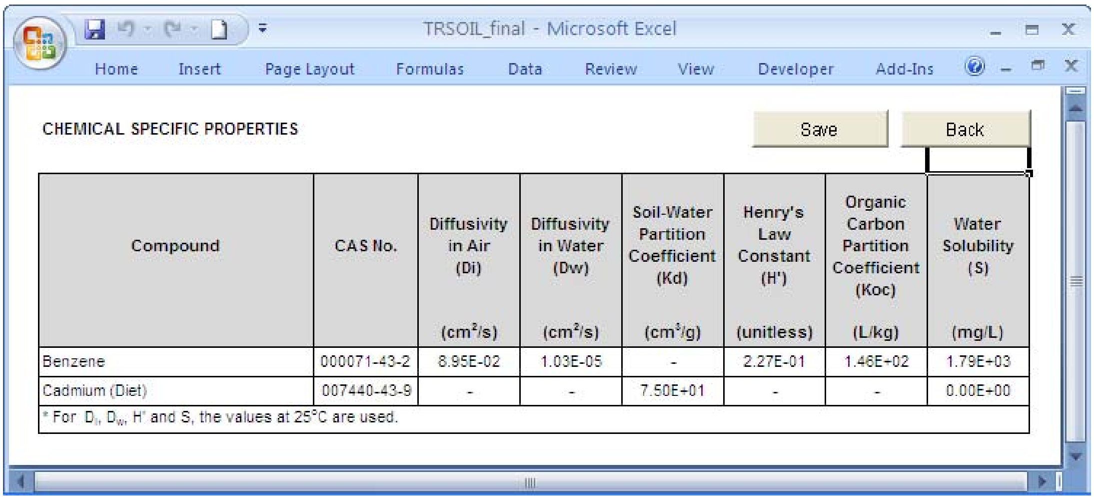
Compound	CAS No.	Acceptable Groundwater Concentration (Cw) (mg/L)	Oral Reference Dose (RfDo) (mg/kg.d)	Oral Cancer Slope Factor (SFo) (mg/kg.d)-1	Inhalation Reference Concentration (RfC) (mg/m^3)	Inhalation Unit Risk Factor (URF) (mg/m^3)$^{-1}$	Gastro-intestinal Absorption Factor (Glabs) (unitless)	Dermal Absorption Factor (ABSd) (unitless)
Benzene	000071-43-2	1.00E-03 [c]	4.00E-03	5.50E-02	3.00E-02	7.80E-03	1.00E+00	-

a) Health Based Limit (HBL).
b) World Health Organization's (WHO's) Drinking Water Standard (WHO, 2008).
c) TS-266 Standard (TSE, 2005).
d) Acceptable groundwater concentration should be multiplied by the corresponding DF (either 1 or 10) in order to obtain C_w to be used in SQS calculations for migration to groundwater pathway.
e) EC: equivalent carbon number.
f) K_d values at pH = 6.8 are given.

Figure 4.13. Output Screen for Human Health Benchmark Values

6) *Cancer Classification and Target Organ/System*: Cancer classification of chemicals and potential organ/system to be affected by any chemical can be viewed. This information are not used in calculations, just given to inform user

about the potential effects of contaminants and to evaluate additive effects of different chemicals on human body (Figure 4.16).

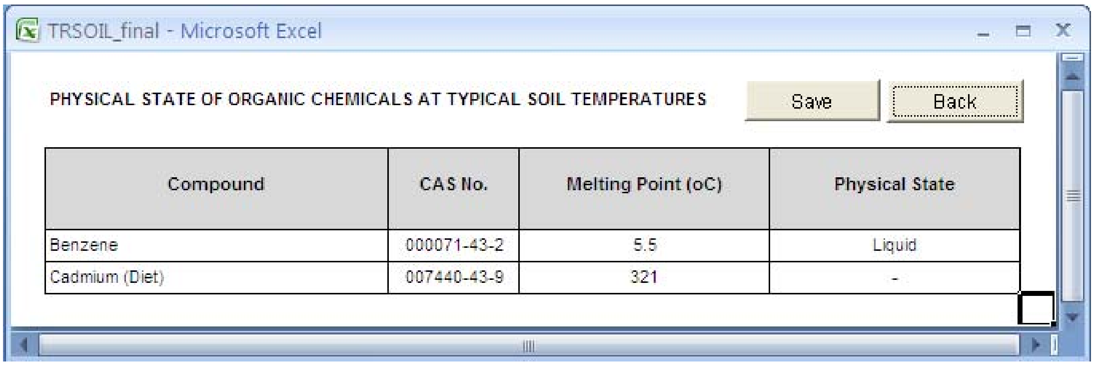


CHEMICAL SPECIFIC PROPERTIES

Compound	CAS No.	Diffusivity in Air (Di) (cm^2/s)	Diffusivity in Water (Dw) (cm^2/s)	Soil-Water Partition Coefficient (Kd) (cm^3/g)	Henry's Law Constant (H') (unitless)	Organic Carbon Partition Coefficient (Koc) (L/kg)	Water Solubility (S) (mg/L)
Benzene	000071-43-2	8.95E-02	1.03E-05	-	2.27E-01	1.46E+02	1.79E+03
Cadmium (Diet)	007440-43-9	-	-	7.50E+01	-	-	0.00E+00

* For D_i, D_w, H' and S, the values at 25°C are used.

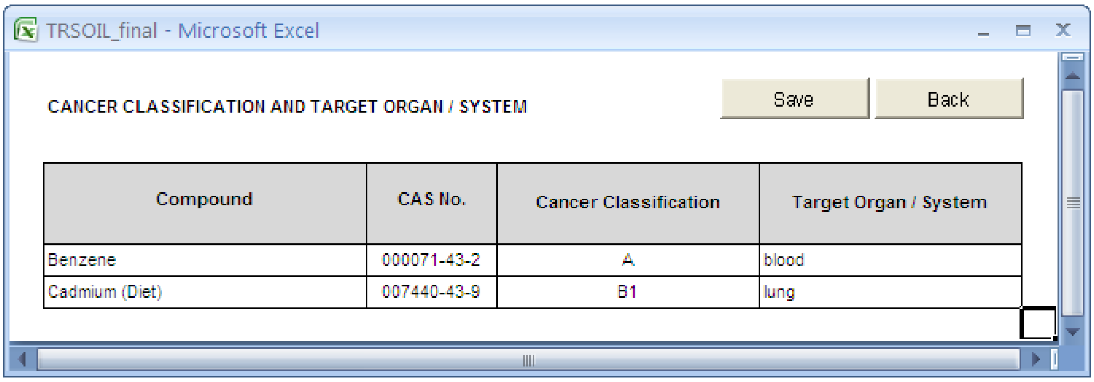
Figure 4.14. Output Screen for Chemical Specific Properties



PHYSICAL STATE OF ORGANIC CHEMICALS AT TYPICAL SOIL TEMPERATURES

Compound	CAS No.	Melting Point (oC)	Physical State
Benzene	000071-43-2	5.5	Liquid
Cadmium (Diet)	007440-43-9	321	-

Figure 4.15. Output Screen for Physical State of Organic Chemicals



CANCER CLASSIFICATION AND TARGET ORGAN / SYSTEM

Compound	CAS No.	Cancer Classification	Target Organ / System
Benzene	000071-43-2	A	blood
Cadmium (Diet)	007440-43-9	B1	lung

Figure 4.16 Output Screen for Cancer Classification and Target Organ/System

4.2.1.2 Database Management

TRSOIL also serves as a database including physico-chemical and human health toxicological data for more than 800 compounds. The compounds in database can be viewed and updated, and new compounds can be added to the database or removed from the database. The database can be maintained in a sustainable manner through use of the buttons in the "Database Management" frame. These buttons are:

1) *View Chemical Properties:* The chemical database contains physico-chemical parameters and toxicity parameters which are used in calculation of SQSs. The information for any chemical can be viewed by selecting the chemical from the dropdown list (Figure 4.17).

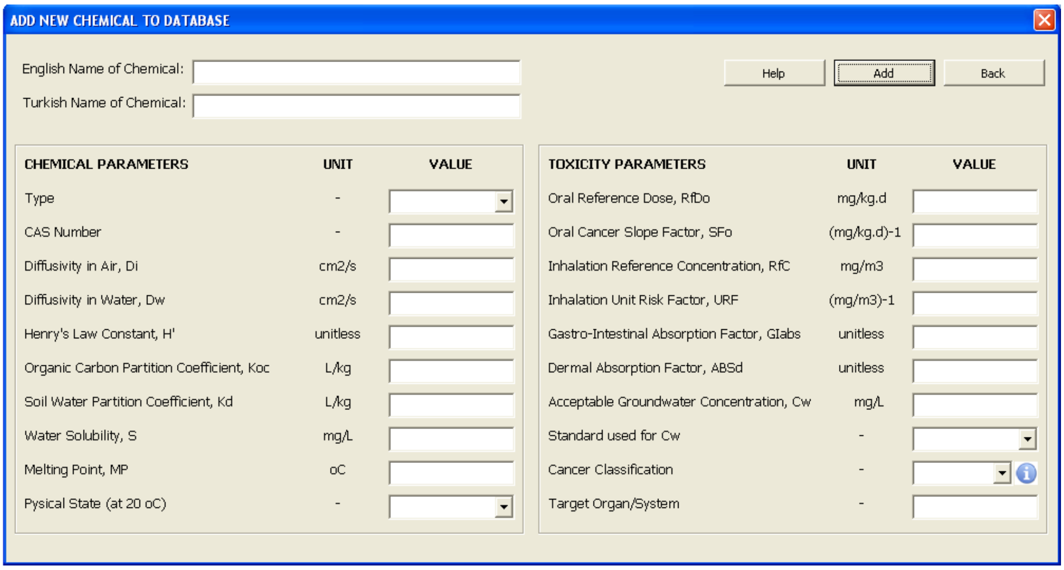
Choose Chemical: Benzene

CHEMICAL PARAMETERS	UNIT	VALUE
Type	-	organic
CAS Number	-	000071-43-2
Diffusivity in Air, Di	cm2/s	0.0895
Diffusivity in Water, Dw	cm2/s	0.0000103
Henry's Law Constant, H'	unitless	0.227
Organic Carbon Partition Coefficient, Koc	L/kg	146
Soil Water Partition Coefficient, Kd	L/kg	-
Water Solubility, S	mg/L	1790
Melting Point, MP	oC	5.5
Pysical State (at 20 oC)	-	Liquid

TOXICITY PARAMETERS	UNIT	VALUE
Oral Reference Dose, RfDo	mg/kg.d	0.004
Oral Cancer Slope Factor, SFo	(mg/kg.d)-1	0.055
Inhalation Reference Concentration, RfC	mg/m3	0.03
Inhalation Unit Risk Factor, URF	(mg/m3)-1	0.0078
Gastro-Intestinal Absorption Factor, GIabs	unitless	1
Dermal Absorption Factor, ABSd	unitless	-
Acceptable Groundwater Concentration, Cw	mg/L	0.001
Standard used for Cw	-	TS-266
Cancer Classification	-	A
Target Organ/System	-	blood

Figure 4.17 View Chemical Information

2) *Add New Chemicals to Database:* New chemicals can be added to TRSOIL database (Figure 4.18). In order to add a chemical to database, physico-chemical and toxicity information should be entered to the corresponding textboxes. To save these records "Add" button should be clicked. If chemical name is not entered, a warning message will appear.



English Name of Chemical:

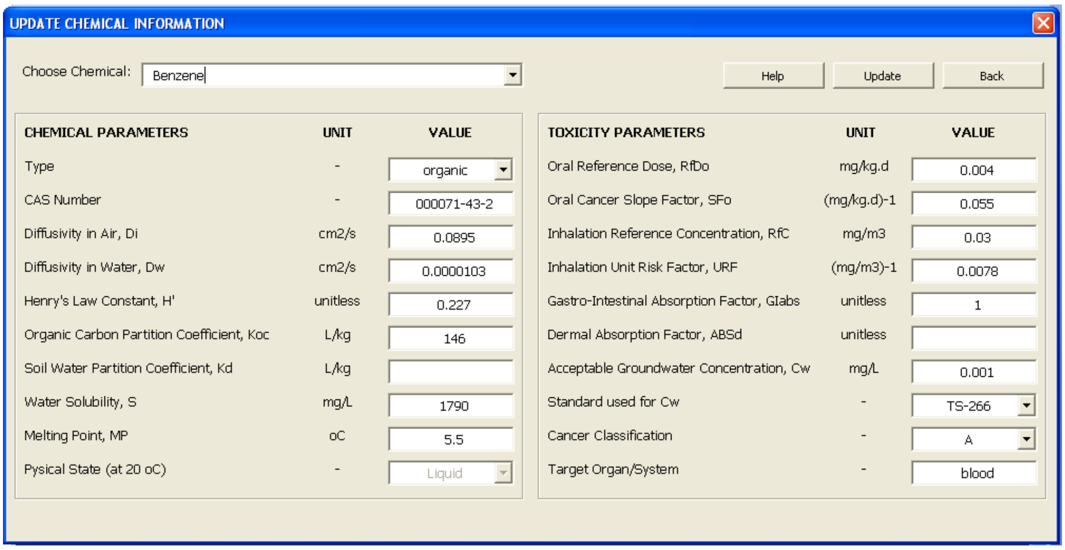
Turkish Name of Chemical:

CHEMICAL PARAMETERS	UNIT	VALUE
Type	-	
CAS Number	-	
Diffusivity in Air, Di	cm2/s	
Diffusivity in Water, Dw	cm2/s	
Henry's Law Constant, H'	unitless	
Organic Carbon Partition Coefficient, Koc	L/kg	
Soil Water Partition Coefficient, Kd	L/kg	
Water Solubility, S	mg/L	
Melting Point, MP	oC	
Pysical State (at 20 oC)	-	

TOXICITY PARAMETERS	UNIT	VALUE
Oral Reference Dose, RfDo	mg/kg.d	
Oral Cancer Slope Factor, SFo	(mg/kg.d)-1	
Inhalation Reference Concentration, RfC	mg/m3	
Inhalation Unit Risk Factor, URF	(mg/m3)-1	
Gastro-Intestinal Absorption Factor, GIabs	unitless	
Dermal Absorption Factor, ABSd	unitless	
Acceptable Groundwater Concentration, Cw	mg/L	
Standard used for Cw	-	
Cancer Classification	-	
Target Organ/System	-	

Figure 4.18 Add New Chemical to Database

3) *Update Chemical Information:* Chemical and toxicity parameters provided in the database can be modified in this page (Figure 4.19). In order to save any modification, "Update" button should be clicked after changing related data.



Choose Chemical: Benzene

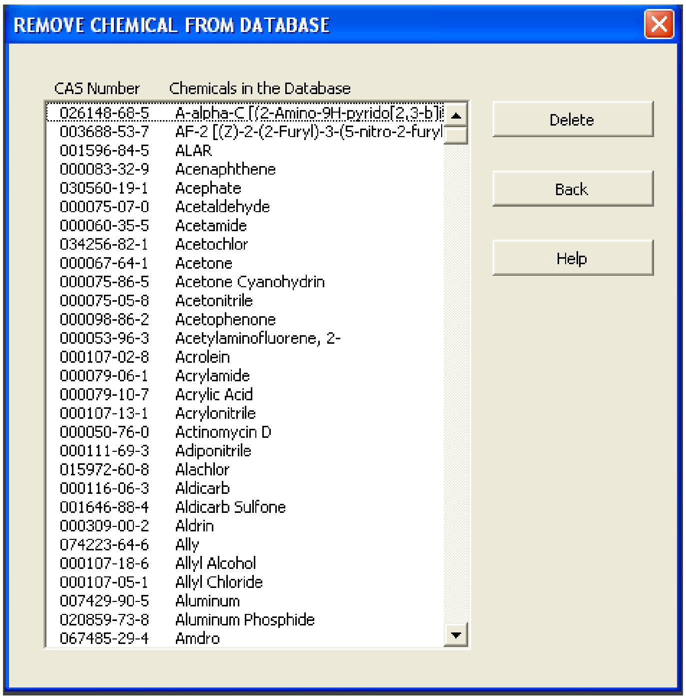
CHEMICAL PARAMETERS	UNIT	VALUE
Type	-	organic
CAS Number	-	000071-43-2
Diffusivity in Air, Di	cm2/s	0.0895
Diffusivity in Water, Dw	cm2/s	0.0000103
Henry's Law Constant, H'	unitless	0.227
Organic Carbon Partition Coefficient, Koc	L/kg	146
Soil Water Partition Coefficient, Kd	L/kg	
Water Solubility, S	mg/L	1790
Melting Point, MP	oC	5.5
Pysical State (at 20 oC)	-	Liquid

TOXICITY PARAMETERS	UNIT	VALUE
Oral Reference Dose, RfDo	mg/kg.d	0.004
Oral Cancer Slope Factor, SFo	(mg/kg.d)-1	0.055
Inhalation Reference Concentration, RfC	mg/m3	0.03
Inhalation Unit Risk Factor, URF	(mg/m3)-1	0.0078
Gastro-Intestinal Absorption Factor, GIabs	unitless	1
Dermal Absorption Factor, ABSd	unitless	
Acceptable Groundwater Concentration, Cw	mg/L	0.001
Standard used for Cw	-	TS-266
Cancer Classification	-	A
Target Organ/System	-	blood

Figure 4.19 Update Chemical Information

4) *Remove Chemical from Database:* Any chemical and its corresponding information can be deleted from the database permanently (Figure 4.20). In order to remove a chemical from the database, chemical should be selected from

the list and "Delete" button should be clicked. Chemicals can be deleted one by one, multiple selection cannot be made.



CAS Number	Chemicals in the Database
026148-68-5	A-alpha-C [(2-Amino-9H-pyrido[2,3-b]
003688-53-7	AF-2 [(Z)-2-(2-Furyl)-3-(5-nitro-2-furyl
001596-84-5	ALAR
000083-32-9	Acenaphthene
030560-19-1	Acephate
000075-07-0	Acetaldehyde
000060-35-5	Acetamide
034256-82-1	Acetochlor
000067-64-1	Acetone
000075-86-5	Acetone Cyanohydrin
000075-05-8	Acetonitrile
000098-86-2	Acetophenone
000053-96-3	Acetylaminofluorene, 2-
000107-02-8	Acrolein
000079-06-1	Acrylamide
000079-10-7	Acrylic Acid
000107-13-1	Acrylonitrile
000050-76-0	Actinomycin D
000111-69-3	Adiponitrile
015972-60-8	Alachlor
000116-06-3	Aldicarb
001646-88-4	Aldicarb Sulfone
000309-00-2	Aldrin
074223-64-6	Ally
000107-18-6	Allyl Alcohol
000107-05-1	Allyl Chloride
007429-90-5	Aluminum
020859-73-8	Aluminum Phosphide
067485-29-4	Amdro

Figure 4.20 Remove Chemical from Database

4.3 RESULTS AND DISCUSSIONS

Calculation of risk based SQSs is not a straight forward process. Different exposure pathways and exposure parameters are incorporated in calculations according to the defined exposure scenarios. Also, various chemical-specific data (physico-chemical and toxicological data) used in calculations increase the possibility of making mistakes. On the other hand, repeating the calculations for different chemicals is a time consuming process. Therefore, to facilitate calculation of generic SQSs and assessment of site-specific soil criteria, development of an exposure model (computational tool) was necessary.

TRSOIL database contains physico-chemical and toxicological data for more than 800 substances. Especially the toxicological data stored in the database needs to be updated with respect to the renovations made by US EPA IRIS, NCEA, etc. Any change in the database can immediately be used to upgrade SQSs. If new chemical information is added to the database, the corresponding SQSs can also be calculated easily by use of TRSOIL.

TRSOIL also serves as a guide for calculation of generic and site-specific SQSs. Since the generic SQSs are derived using conservative assumptions for each land use scenario, the generic standards may be more stringent for the actual site conditions. In this regard, TRSOIL tool would be used not only by the MoEF but also by the other stakeholders in order to calculate site-specific SQSs. Although TRSOIL does not account for risk level calculations, it can be used as a decision tool by comparing the *site-specific SQSs* with the measured soil concentrations.

Although many exposure models are available both in Europe and the US for estimation of risk based limit values, because they are based on different approaches (e.g., use of different assumptions, generic values and terminologies), most of the time it is difficult to calculate SQSs for Turkey. In the developed model, the equations used for calculation of human health risk based Turkish SQSs, generic values for exposure parameters and site characteristics, physical-chemical and toxicological data used in calculations are all integrated. This model also allows changes in parameter values and chemical specific data, in turn, updating risk based SQSs that may be deemed necessary in the future.

TRSOIL has been the first exposure model developed for Turkey in accordance with the national soil pollution control regulation. TRSOIL is exclusive since it is developed with consideration to the generic site characteristics of Turkey and produced for use of the local users in their native language (i.e. Turkish). TRSOIL might be provided for use of the stakeholders (i.e. regulatory agencies, industry, etc.) in the future and might be used for making decisions.

It is a fact that Turkish users sometimes have difficulty in using the exposure models available, since they are not compatible with the procedure of the contaminated sites management system that take place in the Regulation on Soil Pollution Control and Sites Contaminated with Point Sources (MoEF, 2010).

As a result, TRSOIL is considered as a handy tool for calculation of SQSs and for making decisions. It is believed that TRSOIL might constitute the basis and utilized for the development of more detailed risk assessment models in Turkey.

CHAPTER 5

DELINEATION OF GROUNDWATER SYSTEMS AND DEVELOPMENT OF A HYDROGEOLOGICAL DATABASE

In Turkey, groundwater is utilized for domestic use, industrial use and irrigation purposes. Increasing withdrawal of groundwater both by the government and the public, especially for irrigation purposes, designate the prevalence of groundwater use in Turkey. In some cities (e.g., Aydın), the urgent water demand (i.e., tap water) is supplied from groundwater wells by the municipalities.

According to the hydrogeologic investigations performed by the General Directorate of State Hydraulic Works (DSİ) in 2008, the groundwater reserve of Turkey that can be withdrawn safely is 13.66km^3 (DSİ, 2009). DSİ allocated %91 of this groundwater reserve as given in Table 5.1.

Table 5.1 Groundwater Reserve Allocation (DSİ, 2009)

Allocation	**Amount (km^3)**	**Percent (%)**
Irrigation*	4.035	30
Drinking-Utility-Industry	5.647	41
Individual Irrigation	2.737	20
Non-Allocated	1.241	9
TOTAL	13.660	100

*Irrigation by DSİ, public institutions and irrigation cooperatives.

Considering widespread and multi-purpose use of groundwater resources in Turkey, soil contamination takes more attention. Transport of soil contaminants to an underlying aquifer constitutes a significant threat to groundwater quality, and consequently to human health. Because of this reason, it is important to know the distribution of major aquifers within the country and the prevalent soil and hydrogeologic conditions to understand the relation between soil and groundwater and to determine the potential threats to groundwater systems. Such information is also beneficial for management of groundwater resources.

Many research studies have been conducted worldwide to identify the nature and extent of major aquifers in the countries for effective groundwater management. Groundwater occurrence and availability basically depend on the (hydro)geologic properties which are also important for assessment of soil contamination.

As described in Section 2.2.3.4, such soil properties as fraction of soil organic carbon (f_{oc}), water filled soil porosity (θ_w), air filled soil porosity (θ_a), total soil porosity (n), dry soil bulk density (ρ_b) and soil particle density (ρ_s) are needed for estimation of human health risks and calculation of site-specific SQSs for inhalation of volatile emissions from contaminated soil and ingestion of contaminated groundwater. In addition to these parameters, site-specific hydrogeological parameters, such as aquifer hydraulic conductivity (K), hydraulic gradient (i), aquifer thickness (d_a) and infiltration rate (I) are required to calculate the amount of dilution in concentration of a contaminant leaching from soil to groundwater. The knowledge of such parametric data is essential for the estimation of dilution factor (*DF*) and can be made available in a database structure built for this purpose.

The contaminated site assessment is initiated with development of conceptual site model (CSM) which ensures accurate use of site-specific SQSs (US EPA, 1996a). CSM can be described as the illustration of the site conditions and contains information on contaminant source characteristics, site environmental characteristics (i.e., soil characteristics, geological and hydrogeological characteristics), potential exposure pathways and receptors (US EPA, 1996a). A complete CSM developed at the early stages of site assessment ensures the accuracy of site characterization, sampling strategy, and risk assessment. A HGDB which delineates the important groundwater systems and provides the prevailing soil and hydrogeologic parameters for those systems could be utilized for determination of the existence of groundwater resources, migration potential of contaminants from soil to groundwater and the threat to public using groundwater supplies for different purposes.

In this regard, one of the major objectives of this study is to collect easily manageable hydrogeological data at both regional and local scales in a systematic manner and to develop the infrastructure of a HGDB which represents the general soil and hydrogeologic characteristics of a site needed for human health risk assessment studies. The specific purposes to accomplish this objective are

- to identify the hydrogeologic units at regional and local scales, namely groundwater regions, and groundwater bodies within each groundwater region, and
- to develop the descriptive infrastructure of a database specific to each groundwater body within a region.

Ultimately, in mid and long term, this database can potentially lead for derivation of site-specific SQSs regarding migration to groundwater and inhalation of volatiles pathways, estimation of the dilution conditions as contaminants leach from soil to groundwater, development of accurate CSM for contaminated site assessment, sampling strategy and risk assessment purposes. Hence, this HDGB will be the first of its kinds in focusing on soil-groundwater contamination issues in Turkey.

In this regard, the literature review (Section 5.1) discussing the use of a HGDB developed in the US for derivation of generic dilution factor (*DF*), the background for development of that HGDB, the research studies conducted in the US for delineation of groundwater regions, the efforts of EU countries for delineation of groundwater bodies, basic information on geology necessary for groundwater assessment, the content and use of hydrogeological maps for groundwater assessment studies are presented. In Section 5.2, the methodology used for delineation of groundwater regions and bodies, as well as the approach for the development of the structure of a HGDB are described. Finally, in Section 5.3, the results of the study are presented and discussed in detail.

5.1 THEORETICAL BACKGROUND

5.1.1 Use of a HGDB for Development of a Generic Dilution Factor

Chemicals released to soil may leach to the underlying aquifer. The extent of the leaching depends on soil properties and physical/chemical properties of contaminants. Once reached the aquifer, contaminants are diluted by mixing with the ambient groundwater. This level of dilution is called 'dilution factor' (*DF*). As described in Section 2.2.4.3, SQSs for the 'migration to groundwater pathway' are developed based on a generic *DF* and potential risks to human receptors are estimated by calculation of site-specific *DF*.

Two research studies were accomplished by the US EPA in order to figure out the actual dilution rate for real cases. One of these studies was based on the use of the EPACMTP (Composite Model for Leachate Migration with Transformation Products) Model. By use of the unsaturated and saturated zone modules of the EPACMTP model, the migration of contaminants from soil to a down gradient receptor well was simulated (US EPA, 1996a). The data needed for simulations in this study were obtained from nationwide surveys of 1300 waste sites.

The other study was the application of the "simple SSL water balance dilution model" to groundwater sites. For this study, the data obtained from superfund sites contaminated with DNAPL and the American Petroleum Institute's (API's) hydrogeological database (HGDB) (Newell et al., 1990), which was constructed through nationwide surveys, were used.

Based on these studies, a generic dilution-attenuation factor (DAF) range of 10 to 20 was determined as a function of source area. Parameters that affect DAF the most were identified as "climate (infiltration rate), soil types and the size of the contaminated area" (US EPA, 1996a). The details of these studies regarding the input data, the source of input data and results are summarized in Table 5.2.

Table 5.2 Generic Dilution Factor Development Efforts of the US EPA (1996a)

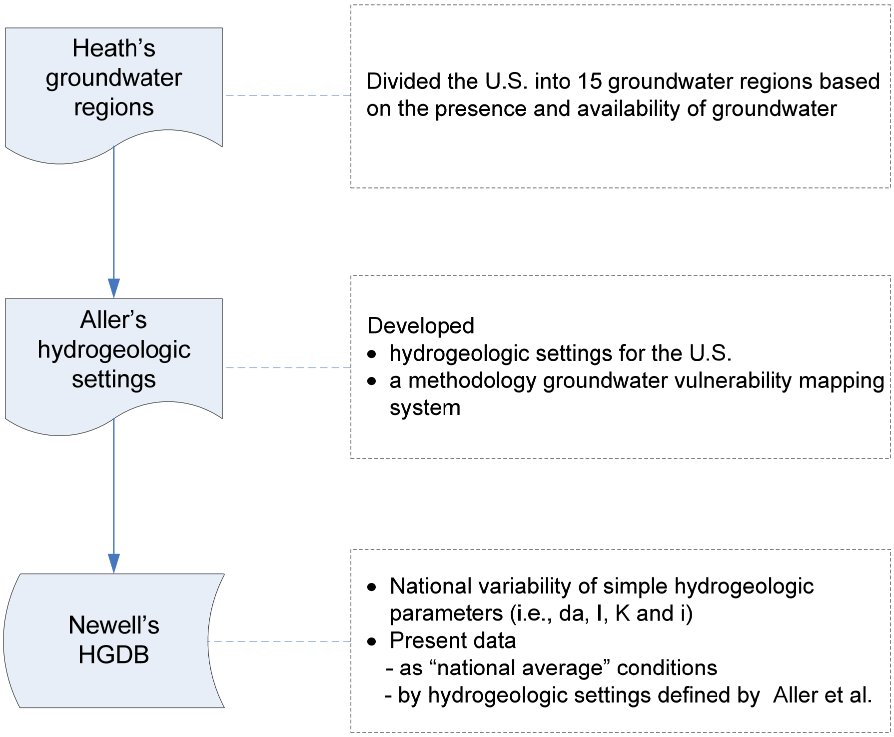
<table>
<tr><td></td><td colspan="3">**EPACMTP MODEL**</td><td colspan="9">**SIMPLE SSL WATER BALANCE DILUTION MODEL**</td></tr>
<tr><td>**INPUTS**</td><td colspan="3">Probability distributions for
• source-specific parameters, e.g., area of the waste unit, infiltration rate
• chemical-specific parameters, e.g., hydrolysis constants, organic carbon partition coefficient
• unsaturated zone-specific parameters, e.g., depth to water table, soil hydraulic conductivity
• saturated zone-specific parameters, e.g., saturated zone thickness, ambient groundwater flow rate, location of nearest receptor well</td><td colspan="9">$DF=1+\frac{Kid}{IL}$
$d=\left(0.0112L^2\right)^{0.5}+d_a\{1-exp[(-LI)/(Kid_a)]\}$
K aquifer hydraulic conductivity (m/yr)
i hydraulic gradient (m/m)
I infiltration rate (m/yr)
L length of source parallel to flow (m)
d mixing zone depth (m)
d_a aquifer thickness (m)</td></tr>
<tr><td>**SOURCE OF INPUTS**</td><td colspan="3">Nationwide surveys of 1300 waste sites</td><td colspan="3">American Petroleum Institute's (API's) hydrogeologic database (HGDB)
(include 208 sites)</td><td colspan="3">EPA's database of conditions at Superfund sites contaminated with DNAPL
(include 92 sites)</td><td colspan="3">All (both API’s HGDB and Superfund Sites contaminated with DNAPL
(include totally 300 sites)</td></tr>
<tr><td>**MODEL RESULTS**</td><td>DAF</td><td>Source Size (ha)</td><td>Protection Level</td><td>DAF</td><td>Source Size (ha)</td><td>Protection Level</td><td>DAF</td><td>Source Size (ha)</td><td>Protection Level</td><td>DAF</td><td>Source Size (ha)</td><td>Protection Level</td></tr>
<tr><td></td><td>**170**</td><td>0.2</td><td>90th percentile</td><td>**16**</td><td>0.2</td><td>geomean</td><td>**34**</td><td>0.2</td><td>geomean</td><td>**20**</td><td>0.2</td><td>geomean</td></tr>
<tr><td></td><td>**7**</td><td>0.2</td><td>95th percentile</td><td>**7**</td><td>12</td><td>geomean</td><td>**10**</td><td>12</td><td>geomean</td><td>**8**</td><td>12</td><td>geomean</td></tr>
<tr><td></td><td>**3**</td><td>12</td><td>90th percentile</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>**CONCLUSION**</td><td colspan="12">**DAF = 10 for a source size of 12ha and DAF = 20 for a source size of 0.2ha**
“In a weight of evidence approach, more weight was given to the results of the DNAPL sites because they are representative of the kind of sites to which SSLs are likely to be applied.” (US EPA, 1996a)
“Climate (net precipitation), soil types and size of contaminated area were determined to be the parameters affecting DAF the most.” (US EPA, 1996a)</td></tr>
</table>

As mentioned earlier, the HGDB developed for API by Newell et al. (1990) was used to provide the hydrogeologic data necessary to run simple water balance dilution model. The database also serves as a useful source of information for estimation of the regional hydrogeologic characteristics, which has to be known in order to derive site-specific soil screening levels (SSLs) for ingestion of groundwater pathway and estimating human health risks. In this regard, API's HGDB (Newell et al., 1990) and Aller et al. (1987) are considered as important data sources (US EPA, 1996a). The regional estimates for the hydrogeologic characteristics (infiltration/ recharge, hydraulic conductivity, hydraulic gradient, aquifer thickness) could be obtained from these data sources.

As mentioned in Section 2.2.4.3, because of the deficiency of such hydrogeological data in Turkey, a generic DF could not be calculated by use of scientific models. The deficiency of such data would probably be noticed during development of CSMs and sampling strategies for the generic and site-specific risk assessment studies to be performed within the context of the regulation on Soil Pollution Control and Sites Contaminated by Point Sources (MoEF, 2010). Therefore, the existence of such information sources in the US points out the need for a HGDB including the regional hydrogeological characteristics of Turkey. In this respect, a literature review was conducted to reveal the background for development of a HGDB.

5.1.2 Background for the API's HGDB Development Studies

API's HGDB was developed by Newell et al. (1990) primarily "to collect actual contaminated site data in a database and to produce national distributions for aquifer parameters" (US EPA, 1996a). The database was structured based on the hydrogeologic settings defined by Aller et al. (1987) for "development of a groundwater vulnerability mapping system". Aller et al. (1987) defined the hydrogeologic settings within the groundwater regions delineated by Heath (1984). The subsequent studies starting with delineation of groundwater regions and ending with development of the HGDB is illustrated in Figure 5.1 and the details of these studies are described in the following paragraphs.



Divided the U.S. into 15 groundwater regions based on the presence and availability of groundwater

Developed
- hydrogeologic settings for the U.S.
- a methodology groundwater vulnerability mapping system

- National variability of simple hydrogeologic parameters (i.e., da, I, K and i)
- Present data
  - as "national average" conditions
  - by hydrogeologic settings defined by Aller et al.

Figure 5.1 Illustration of Hydrogeological Database Development Studies

Development of the API's HGDB (Newell et al., 1990)

The structure of the database was established based on the hydrogeologic settings defined by Aller et al. (1987). Hydrogeological data gathered through field investigations were compiled through a questionnaire including questions on contaminated site location, hydrologic characteristics, aquifer characteristics, geologic characteristics and source characteristics (Hopkins, 1989). The groundwater professionals of the Association of Ground Water Scientists and Engineers in the US were attended the survey (Hopkins, 1989). After collecting the data, the distributions for parameters, such as hydraulic conductivity, hydraulic gradient, seepage velocity, saturated thickness, and depth to top of aquifer were determined. The national average conditions for each of the hydrogeologic settings defined by Aller et al. (1987) were produced.

Definition of the Hydrogeologic Settings in the US (Aller et al., 1987)

Aller et al. (1987) developed a methodology for development of a groundwater vulnerability mapping system that allows estimation of the pollution potential of any hydrogeologic unit. Aller et al. (1987) defined the hydrogeologic units (i.e., hydrogeologic settings) based on 12 different hydrogeologic environment groups (Freeze et al., 1979) that take place within each groundwater region delineated by Heath (1984) and called these units as ‘hydrogeologic settings’. .

In the groundwater vulnerability mapping system, “the hydrogeologic settings represent the geologic and hydrogeologic factors that control groundwater movement into and out of the area and they are used as the mappable units” (Aller et al., 1987). These major hydrogeologic factors (listed as **D**epth to Water, Net **R**echarge, **A**quifer Media, **S**oil Media, **T**opography, **I**mpact of Vadose Zone Media, Hydraulic **C**onductivity of the Aquifer) controlling groundwater movement are incorporated to the system to calculate a vulnerability index for each setting (Aller et al., 1987). Consequently, a DRASTIC index value is provided for each hydrogeologic setting which could reflect the level of vulnerability of hydrogeologic setting to groundwater contamination (Aller et al., 1987).

Delineation of the Groundwater Regions (Heath, 1984)

Heath (1984) divided the US into 15 groundwater regions which are similar in terms of presence and availability of groundwater. Heath (1984) states that “the presence and availability of groundwater depend primarily on geologic conditions, thus groundwater regions are areas in which the composition, arrangement, and structure of rock units are similar”. Heath (1984) used the nature and extent of the dominant aquifers and their relations to other units of the groundwater system as the primary criteria for delineation of groundwater regions. Thus, Heath (1984) determined the main physical and hydrologic characteristics of each region and produced the common ranges of values for the hydraulic characteristics, such as transmissivity, hydraulic conductivity, recharge rate, and well yield.

The groundwater regions of Heath (1984) and hydrogeologic settings of Aller et al. (1987) are incorporated to the HGDB developed by Newell et al. (1990). Newell et al. (1980) utilized these classifications for development of the structure of the HGDB. For each hydrogeologic setting, aquifer parameters, such as hydraulic conductivity, hydraulic gradient, seepage velocity, saturated thickness, and depth to top of aquifer were entered to the database (Hopkins, 1989; Newell et al., 1990).

5.1.3 EU Approach to Delineation of Groundwater Bodies

In concern with the studies performed in the US, the approach of EU to identification of hydrogeologic units was assessed. This section describes the approaches of EU Member States to delineation of hydrogeologic units.

In Europe, the research studies related to identification of hydrogeologic units have been performed in conjunction with the EU directives. EU Water Framework Directive (WFD) (EU COM, 2000), which states strategies for protection of inland surface waters, transitional waters, coastal waters and groundwater, was entered into force in 2000. According to WFD, all Member States are required "to implement measures necessary to prevent or limit pollution of groundwater, to protect, enhance and restore all groundwater bodies, and to reverse any significant deterioration resulting from human activity to achieve good groundwater status (both qualitatively and quantitatively" until 2015 (EU COM, 2000). In 2006, Groundwater Daughter Directive (GWD) (EU COM, 2006) was adopted as a complementary directive to WFD. The directive specifies the measures for protection of groundwater against deterioration by introducing the criteria for assessment of groundwater status. One of the criteria for achieving good groundwater status (both quantitatively and chemically) mentioned by WFD (EU COM, 2000) is the definition and characterization of management units called '*groundwater bodies*' within the river basin districts (because water management is considered based on river basins). More specifically, groundwater body is defined as "*a distinct volume of groundwater within an aquifer or aquifers*" by WFD (EU COM, 2000). Identification of groundwater bodies is not considered as the ultimate objective, but as a tool to describe quantitative and chemical status of a body appropriately.

For identification of groundwater bodies, the main considerations proposed by Common Implementation Strategy (CIS) for WFD (EU COM, 2004) are (i) consideration of the boundaries that groundwater flow from one body to another is negligible, which ensures assessment of the quantitative status of the body (aquifer properties are proposed to be used for this purpose) (ii) consideration of the boundaries between different formations (e.g., karst and sandstone) due to different management approaches they require.

Moreover, analysis of groundwater bodies is stipulated by the WFD in order to assess the groundwater use and the groundwater bodies at risk for implementation of necessary protective measures (EU COM, 2000). This analysis involves initial and further characterization. For initial characterization, hydrological, geological, pedological, land use, discharge, abstraction properties has to be figured out by identifying the groundwater bodies, the sources of pollution threatening the groundwater bodies, the general characteristics of the overlying strata, and the surface water ecosystems or terrestrial ecosystems that have relation with the groundwater bodies (EU COM, 2000). For groundwater bodies that are considered to be at risk, further characterization is required to define the measures necessary to protect good groundwater status. This characterization basically involves information on "geologic characteristics, hydrogeological characteristics (including aquifer parameters and confinement), characteristics of the overlying strata (e.g., deposits and soil, hydraulic conductivity, porosity, absorptive properties of soil), surface water systems and its relation to groundwater body/bodies, data to calculate recharge rates, and chemical characterization of the groundwater" (EU COM, 2000).

Regarding the requirements of WFD, the EU started a two-year project in 2005 called BRIDGE (**B**ackground C**R**iteria for the **ID**entification of **G**roundwater Thr**E**sholds). The aim of BRIDGE project was to develop a methodology for derivation of pollutant threshold values for groundwater bodies and to assess the status of groundwater bodies in terms of quality and quantity criteria. The project was carried out at European level, involving a range of stakeholders from 17 countries (Austria, Belgium, Bulgaria, Denmark, France, Estonia, Germany, Hungary, Italy, The Netherlands, Poland, Portugal, Spain and United Kingdom) (URL 2). Under work package 2 (Impact of Hydrogeological Conditions on Pollutant Behavior in Groundwater and Related Ecosystems) of the project, the methodology developed by each country for delineation of groundwater bodies was examined (BRIDGE, 2006). The studies performed by BRIDGE working group pointed out that "the hydrographical limits, the hydrogeological parameters and -depending on the countries- the water use" has been considered for delineation of groundwater bodies (BRIDGE, 2006):

In the Workshop on Groundwater Bodies, which was held by Federal Institute for Geosciences and Natural Resources (BGR) and EurGeoSurveys (EGS) in 2005 in

Berlin, the approaches for delineation and characterization of groundwater bodies were discussed in relation to the requirements of WFD (URL 16). About 70 experts from 24 countries shared their experiences related to the methodology used for delineation of groundwater bodies. The general conclusion drawn up was that the groundwater bodies have to be uniform with regard to hydrogeology (structure), flow conditions (hydraulics) and properties (quality) (URL 16). Besides, the experts agreed on delineation of groundwater bodies within each river basin to allow management of the groundwater with regard to its quantitative and qualitative status (URL 16).

5.1.4 Groundwater Geology

As mentioned in the previous sections, it is necessary to understand the relation between geology and occurrence of groundwater for delineation of groundwater regions and groundwater bodies. In this respect, this section presents the basic information on groundwater geology.

Groundwater is stored in the openings present in the rocks that cover the Earth's crust. The mineral composition and structure of the rocks controls the size and volume of the water holding openings and the other water-bearing characteristics of the rocks. In landscape scale, the quantity and availability of groundwater then depends on the geology; and hence, the nature and distribution of aquifers and aquitards are strongly related with the lithology (physical make up, mineral composition, grain size and grain packing), stratigraphy (arrangement, age relations between formations), and structural features (e.g. openings such as pores, cleavages, fractures, folds and faults) (Heath, 1984; Freeze et al., 1979).

In order to understand these water-bearing characteristics of rocks, first of all, it is necessary to discuss major rock groups, the occurrence and distribution of which on the Earth's crust can be best described by rock cycle (Heath, 1984). Geologists divide rocks into three main groups according to their mode of formation. These rock groups are igneous rocks, sedimentary rocks and metamorphic rocks. Each rock group includes different rock types which differ based on the composition, texture, and thus in terms of water bearing characteristics (Monroe et al., 1995; Heath, 1984). Rock cycle given in Figure 5.2 relates the rock groups to each other.

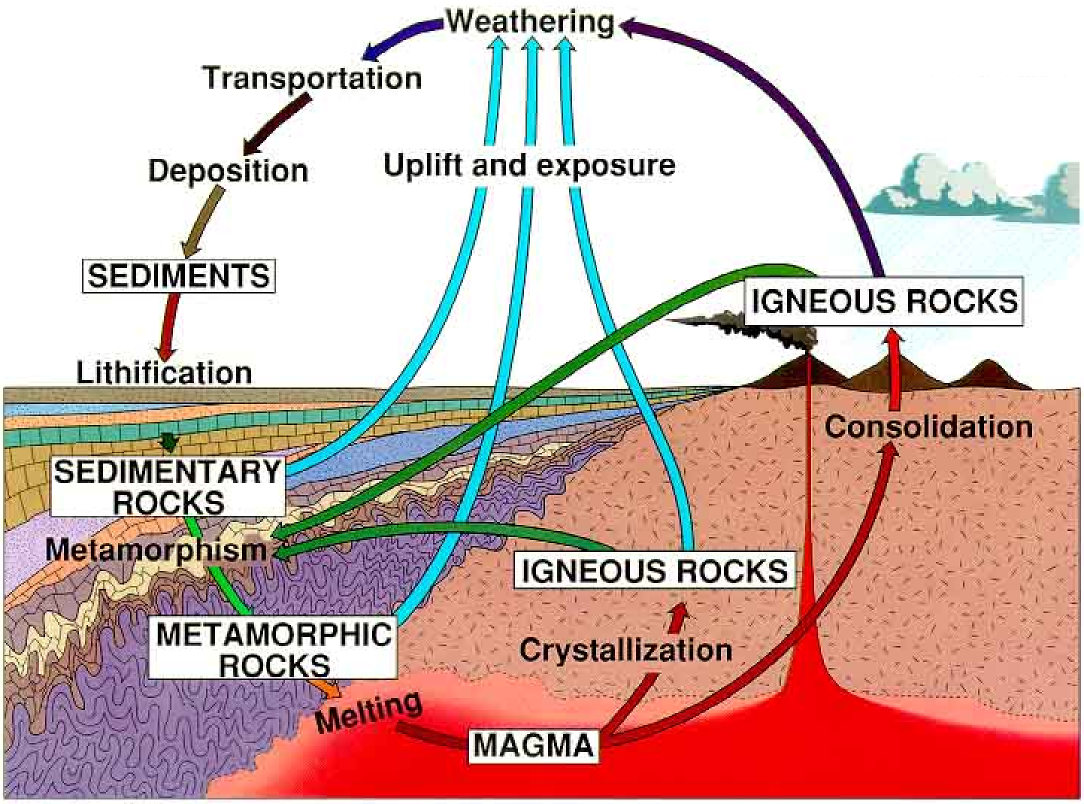


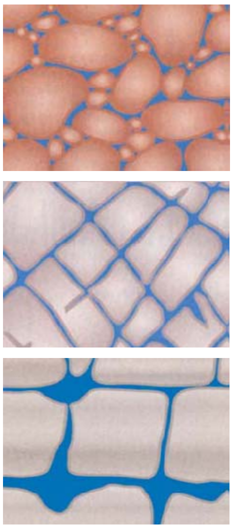
Figure 5.2 The Relation between Major Rock Groups (Monroe et al., 1995)

Igneous rocks result from crystallization of magma or from the accumulation and consolidation of volcanic ejecta such as ash. Extrusive igneous rocks, such as basalt and andesite, result from solidification of magma at earth's surface, whereas intrusive igneous rocks, such as granite, diorite, gabbro, form as magma cools slowly beneath earth's surface (Monroe et al., 1995). Rocks subjected to various weathering processes may eventually deposit as sediment which may be compacted and cemented to form sedimentary rocks. Other process that form sedimentary rocks are precipitation of mineral matter from solution or compaction of animal or plant remains (Monroe et al., 1995). As could be understood from the name, metamorphic rocks are formed from metamorphism of other rocks by heat, pressure, and chemical activity of fluids. Marble, gneiss and schist could be given as examples to this group of rocks.

Each rock group has different water-bearing characteristics. For example, fine-grained igneous rocks are called as aphanitic, which results from rapid cooling of magma, and form water-bearing extrusive igneous rocks, such as basalt and andesite. On the other hand, slow cooling results in coarse-grained (phaneritic) texture (Monroe et al., 1995). Granite and gabbro are typical intrusive igneous rocks that have phaneritic texture. Metamorphic rocks do not contain significant capacity to hold groundwater at the time of their formation (Heath, 1984). However, the compressive forces exerted on the metamorphic rocks, which are formed at great depths beneath the earth surface, results in sets of horizontal and vertical fractures acting as water-bearing openings (Heath, 1984).

Similar fractures can also be observed at sedimentary rocks that have been deeply buried and consolidated (e.g. limestone and dolomite). On the other hand, unconsolidated sedimentary deposits (e.g. sand and gravel) that are not hardened by mineral cement, pressure or thermal alteration have capacity to hold groundwater within pores (Heath, 1984). Another important criterion that affects the water-bearing capacity of sedimentary rocks is the geologic age of the rocks. Younger sedimentary rocks tend to have larger volume of openings compared to older rocks of the same group, since they are subjected to relatively low consolidation (Heath, 1984).

The openings in rocks are referred either as primary or secondary openings. Primary openings are the voids that were formed at the time of rock formation (Figure 5.3a), whereas secondary openings were formed after rock formation, such as fractures (Figure 5.3b) or cavities (Figure 5.3c).



a) Intergranular flow occurs through the voids (pore space) between individual mineral grains. This type of flow is typical for rock consisting of unconsolidated deposits (e.g. loose gravel, sand or silt).

b) In hard rock, groundwater can be transmitted through fissures or fractures. If the primary porosity is small groundwater flow is virtually restricted to fissures.

c) As rock dissolves along fractures or bedding planes large cavities and even caves can develop. This leads to the development of “karst” formations in which groundwater can drain quickly. Karst is usually developed in carbonate rocks such as limestone and dolomite. Groundwater is often abundant in these formations, but can almost as easily be polluted as surface streams.

Figure 5.3 Groundwater Flow Regimes (Nkhoma et al., 2007)

5.1.5 Hydrogeological Maps

The principal geologic properties that affect the occurrence of groundwater are described in the previous section. These stratigraphical and lithological properties of outcropping rock units are presented by geological maps. Whereas hydrogeological maps, which are produced by combination of the geological information with the hydrological (water) information based on topographical maps, designate the distribution of groundwater systems within the country (Struckmeier et al., 1995). In this section, the background for development of hydrogeological maps and the contents of the hydrogeological maps are described.

The production of hydrogeological maps was initiated in 1940s in many countries at different scales in regard to the increasing water demand (Struckmeier et al., 1995). Since then hydrogeological maps are considered as useful tools for planning of water resources (Struckmeier et al., 1995). However, there was no consistency between the maps produced by different parties. In order to satisfy the uniformity in mapping (use of uniform symbols, ornaments and colors), the General Assembly of International Association of Hydrogeological Sciences (IAHS) and the International Association of Hydrogeologists produced an international hydrogeological map legend in 1959 (Struckmeier et al., 1995). The first draft of the legend was accepted by "United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Food and Agriculture Organization (FAO), the Commission for the Geological Map of the World (CGMW), and interested parties of many nationalities and published by UNESCO" (Struckmeier et al., 1995).

Following that, "the European international small-scale hydrogeological map project" was initiated to harmonize hydrogeological representations and to promote mapping activities worldwide (Struckmeier et al., 1995). It was decided to compile the hydrogeological maps of the countries at 1:1,500,000 scale as the Geological Map of Europe, with the same grid of map sheets, topographic detail and projection (Struckmeier et al., 1995).

As a result of these studies, the International Hydrogeological Map of Europe (IHME) (given in Figure 5.4) was produced in 1960s. Explanatory notes were also printed in addition to the map sheets in most of the countries. The information that could not be placed on the map, such as cross-sections, hydrographs, tables, and other graphics are given in the explanatory notes (Struckmeier et al., 1995).

As can be seen from Figure 5.4, IHME also covers the Western part of Turkey. 1:500,000 scale hydrogeological map of Turkey has been prepared by General Directorate of State Hydraulic Works (DSİ) in 1967 for the first time. The geological map of Turkey prepared by the Mining Research and Exploration Institute (MTA) was utilized for preparation of the hydrogeological map. Considering that 1:1,500,000 scale hydrogeological map of Turkey prepared during the late 1960s and its consistency with the projection system used, it may be concluded that the map has been produced for the European international small-scale hydrogeological map project and integrated to the IHME. However, no explanatory notes have been published for the hydrogeological map of Turkey so far.

On the other hand, the hydrogeological map of Turkey included in the IHME covers only half of the country. Because 1:1,500,000 scale hydrogeological map of Turkey has been prepared only for this part of the country (Figure 5.5). On the other hand, 1:500,000 scale hydrogeological map has been prepared in those years for the whole country.

While interpreting the geological maps for hydrogeological mapping, litho-stratigraphical units are converted to hydro-lithological units and the boundaries of the groundwater flow systems are defined by geology and structure (Struckmeier et al., 1995). Therefore, hydrogeological maps present information on the properties and interrelations between groundwater and rocks in conjunction to topography (Struckmeier et al., 1995). It includes information on the occurrence of groundwater, as well as the movement, quantity and quality of the groundwater. However, the information gathered in the map depends on the scale of the map. Small scale maps show only the general location and disposition of aquifers and non-aquifers, and usually do not include information on the vertical cross-sections. The hydrogeological maps can be distinguished with respect to the level of information contained and the possible uses as given in Table 5.3.

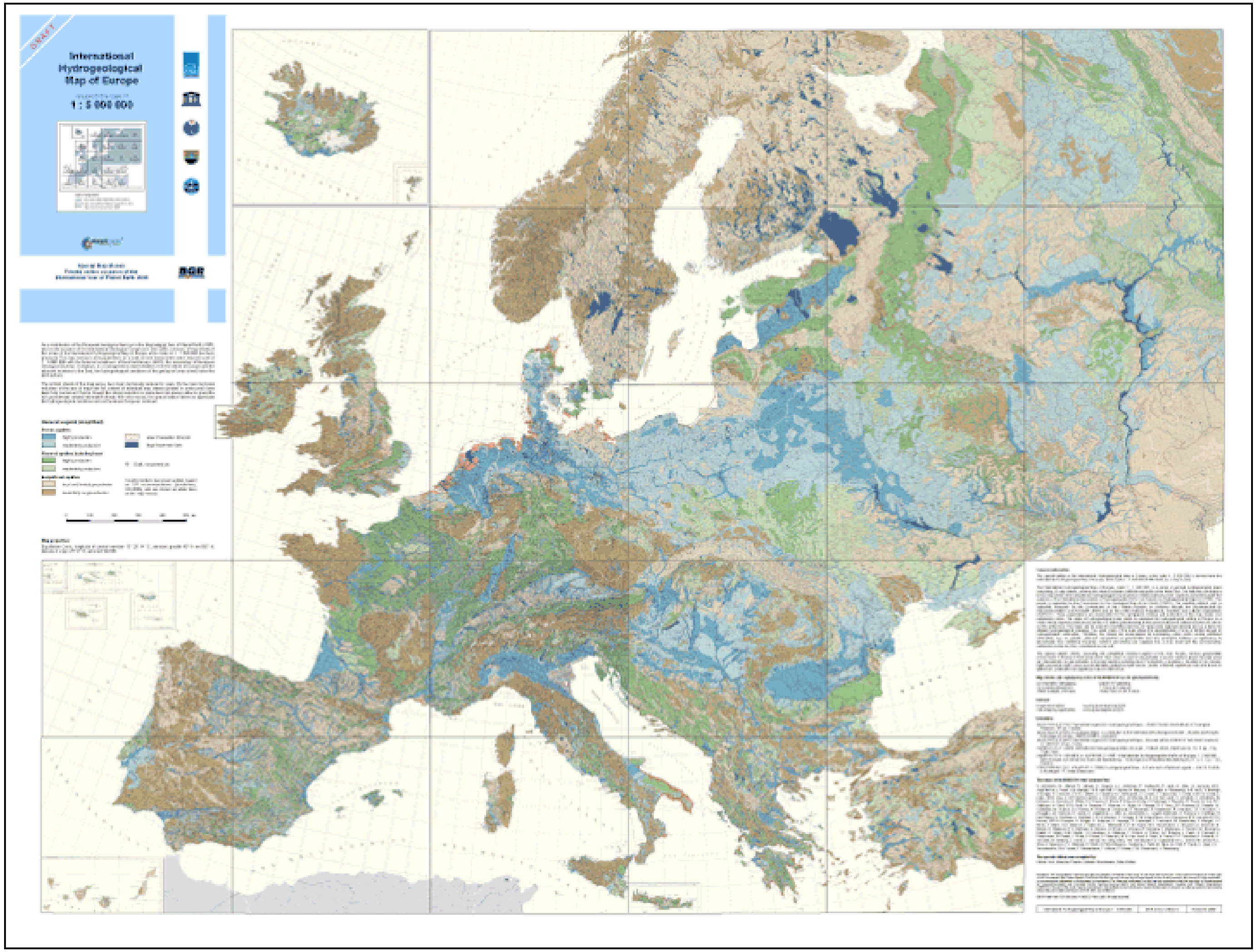


Figure 5.4 International Hydrogeological Map of Europe (URL 14)

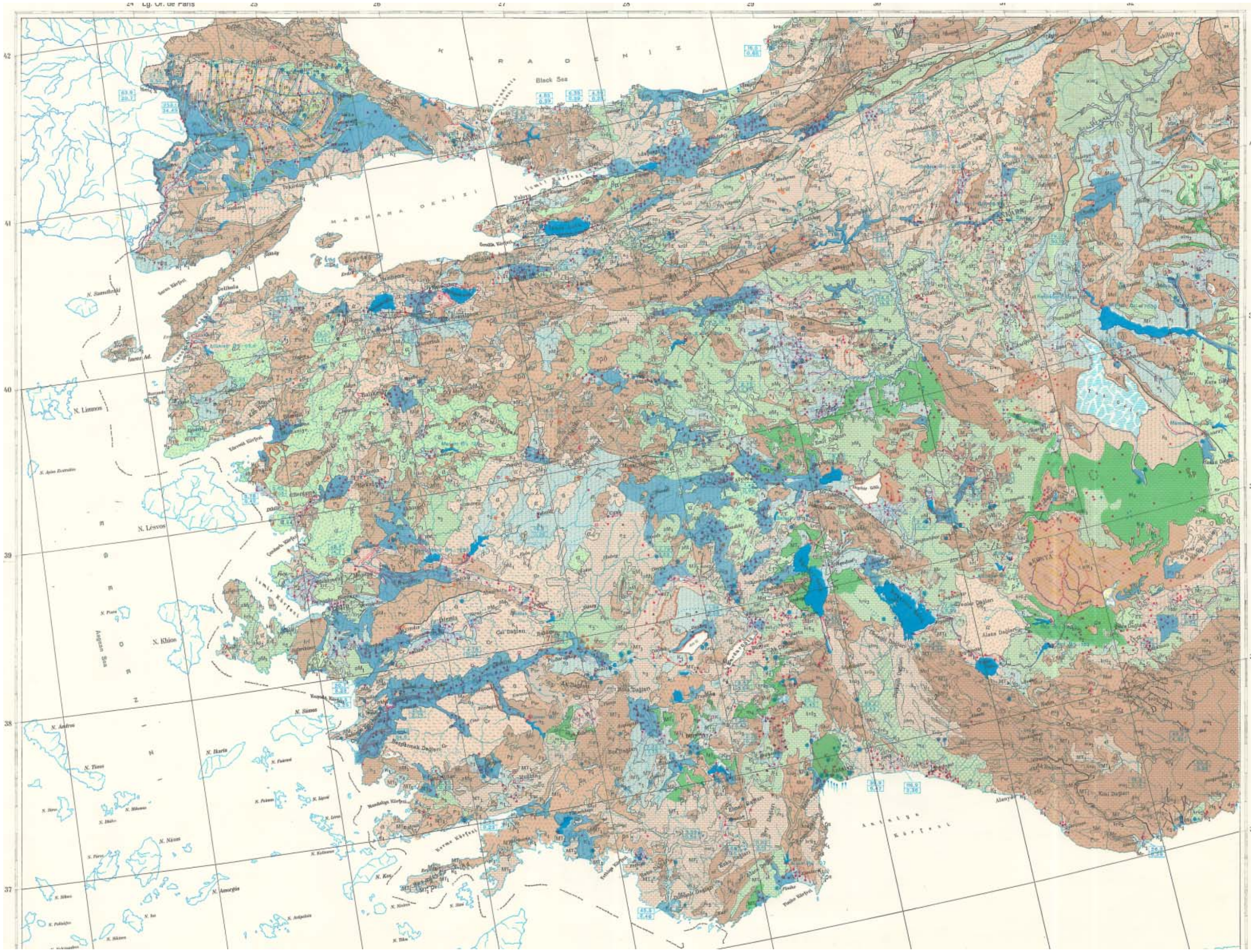


Figure 5.5 1:1,500,000 Scale Hydrogeological Map of Turkey (DSİ, 1971)

Table 5.3 Classification of Hydrogeological Maps (Struckmeier et al., 1995)

level of information / **possible use**	**low (scarce and heterogeneous data from various sources)**	**advanced (+ systematic investigation programmes, more reliable data)**	**high (+ hydrogeological systems analysis and groundwater models)**
reconnaissance and exploration	general hydrogeological map (aquifer map)	hydrogeological parameter maps (map sets, atlases)	regional groundwater systems maps (conceptual model representations)
planning and development	map of groundwater resource potential	specialized hydrogeological maps (planning map)	graphic representation derived from geographic information systems (maps, sections, perspective diagrams, scenarios)
management and protection	map of groundwater vulnerability		
possible use / **parameters of representation**	static ------------ time-dependence ----------------→dynamic low -------------------- reliability ---------------------→high low --------------- cost per unit area ----------------→ high large ←------------ area represented ------------------- small small -------------------- scale -----------------------→ large		

In hydrogeological maps, the formations are shown under three major groups with respect to their groundwater productivity: (1) unconsolidated formations (granular aquifer material in which flow occurs mainly through the pores), (2) consolidated formations (fissured aquifer, including karst aquifer), and (3) formations do not containing groundwater or containing local (perched) groundwater (stratum forming insignificant aquifer) (Struckmeier et al., 1995). These main groups are classified further and each class is colored as shown in Figure 5.6. In fact, this classification indicates the groundwater flow regime (intergranular or fissured) and the aquifer potential (productivity and lateral extent) (Nkhoma et al., 2007). Blue colors indicate systems of intergranular flow, and green colors indicate flow occurring in fissures, fractures or dissolution cavities (Nkhoma et al., 2007). The darker tones of blue and green represent extensive and highly productive aquifers, whereas lighter tones represent local resources and moderate productivity (Struckmeier et al., 1995). Light brown is used for formations that might have limited or local groundwater resources (aquitards), and dark brown is used for formations with no usable groundwater (aquicludes and aquifuges) (Struckmeier et al., 1995; UNESCO, 1983).

In Europe, IHME is regarded as a useful tool for representation of the hydrogeologic settings and it is used as a background document to fulfill the requirements of EU WFD (Struckmeier et al., 2005). The map is utilized in

Europe for groundwater management and in some European countries for delineation of the groundwater bodies (Struckmeier et al., 2005).

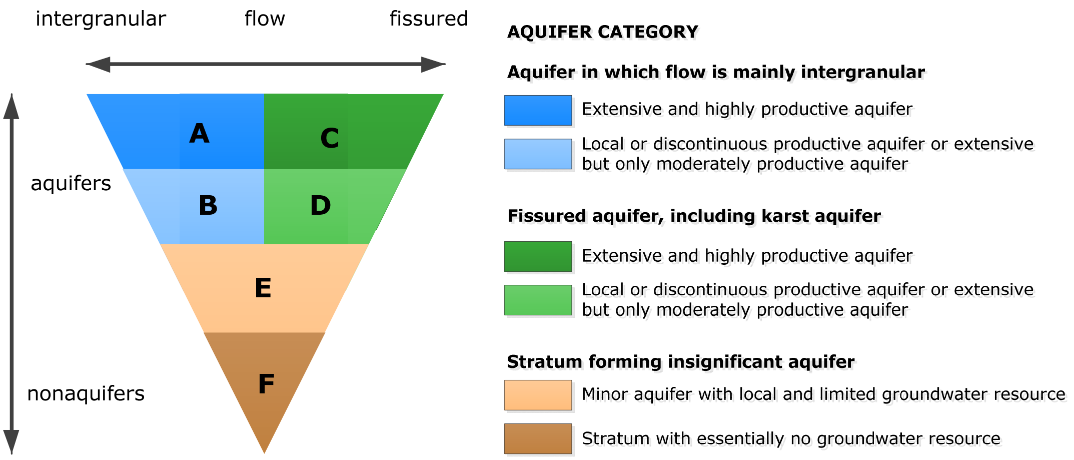


Figure 5.6 Aquifer Classification System (Struckmeier et al., 1995; Nkhoma et al., 2007)

5.2 METHODOLOGY

With the insight gained from the sequence of studies performed by Heath (1984), Aller et al. (1987), Hopkins (1989) and Newell et al. (1990) (described in Section 5.1.2), the structure of the HGDB for Turkey was decided to be established based on the hydrogeologic units to be identified. In this respect, Heath's approach for delineation of groundwater regions was considered to be appropriate for identification of the regional hydrogeologic units, namely groundwater regions. On the other hand, EU approach was utilized for delineation of local hydrogeologic units, i.e., groundwater bodies, within each groundwater region. For delineation of the groundwater regions and bodies, the hydrogeological map, which is designates the aquifer and non-aquifer properties of formations, was decided to be used in regard to the groundwater delineation studies performed by EU countries (described in Section 5.1.3). The structure of the HGDB was then developed by use of Geographical Information System (GIS) features for the mapping units, i.e., groundwater bodies and groundwater regions. As shown in Figure 5.7, the study of HGDB development for Turkey is comprised of three phases. The first phase involves development of a methodology for delineation of groundwater regions where the composition (lithology), arrangement (stratigraphy) and structural features (pores, fractures, folds, or faults) are similar (Heath, 1984).

The second phase involves development of a methodology for delineation of the hydrogeologic units within each groundwater region, called as “groundwater bodies”, which represent similar composition, arrangement, structure and groundwater productivity (aquifer and non-aquifer properties), such as groundwater (natural) quality and quantity. The third phase of the study consists of developing a descriptive database infrastructure specific to delineated groundwater bodies, which provides the data needed to derive site-specific SQSs, to estimate site-specific dilution factor (*DF*), to assess site-specific risks, to build CSM and sampling strategy during contaminated site assessment studies.

In the following Sections, the properties of the hydrogeological map used for the study (Section 5.2.1); the relation between groundwater occurrence and geologic features (Section 5.2.2); the approach used for delineation of groundwater regions (Section 5.2.3) and groundwater bodies (Section 5.2.4); and development of the descriptive infrastructure specific to groundwater bodies (Section 5.2.5) are described.

5.2.1 Hydrogeological Map Used for the Study

Since hydrogeological maps include information on the occurrence of groundwater and the disposition of aquifers, hydrogeological map of Turkey was determined to be the most appropriate map for delineation of groundwater regions and groundwater bodies. One of the primary focuses of this study was to develop a robust methodology for delineation of groundwater regions and groundwater bodies. Currently, only the western part of country, where potential soil contaminating activities are observed frequently, was studied for this purpose. However, the methodology developed in this thesis is generic and applicable to the entire country. Future studies would be extended to cover the rest of the country. Considering the potential studies in this field, it was decided to work on 1:500,000 scale hydrogeological map, instead of 1:1,500,000 scale map which has not been prepared for the eastern part of the country. Hydrogeological map of Turkey at a scale of 1/500.000 consists of 18 sheets, of which 9 sheets cover the Western and Central Anatolian regions of Turkey. These 9 sheets were digitized for this study as the base map for development of Turkish HGDB, delineating the groundwater regions and groundwater bodies. The study area used for the development of HGDB methodology is seen in Figure 5.8.

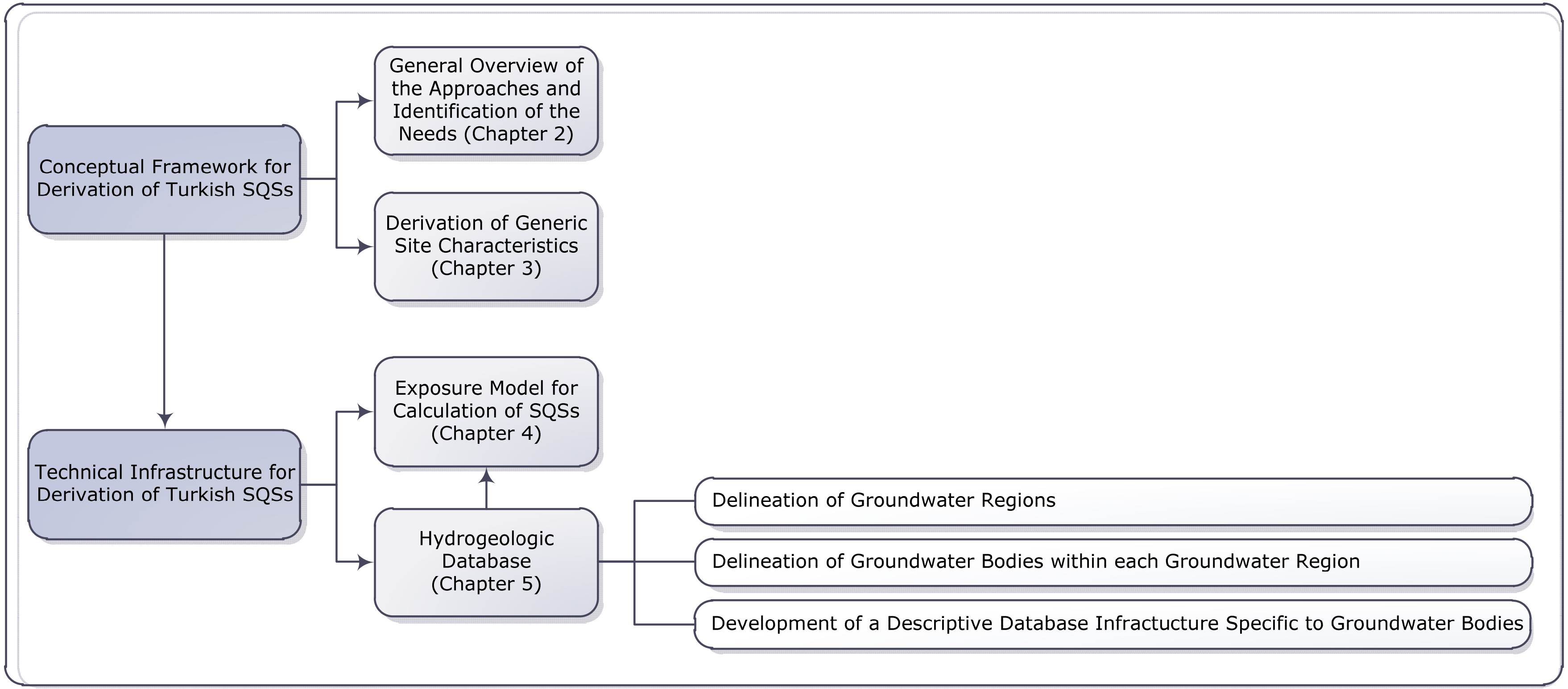


Figure 5.7 Framework of the Study for the HGDB Development

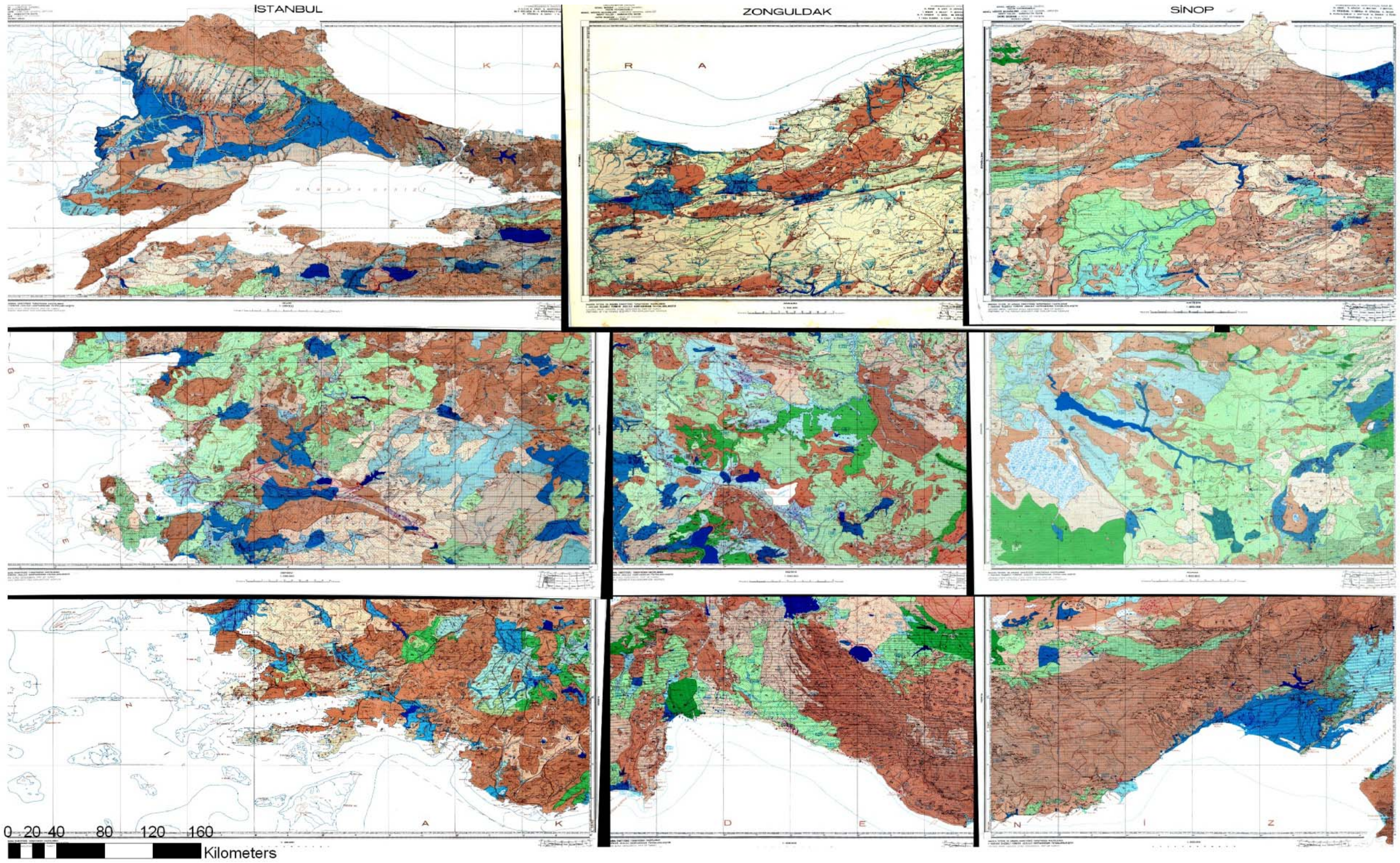
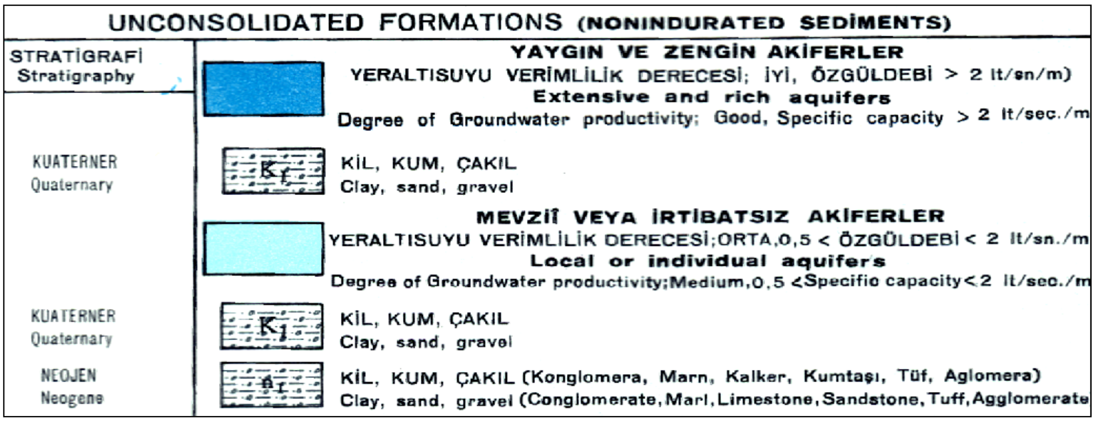


Figure 5.8 Study Area used for the Development of HDGB - 9 Sheets of Hydrogeological Map of Turkey with a Scale of 1/500,000 (DSİ, 1967)

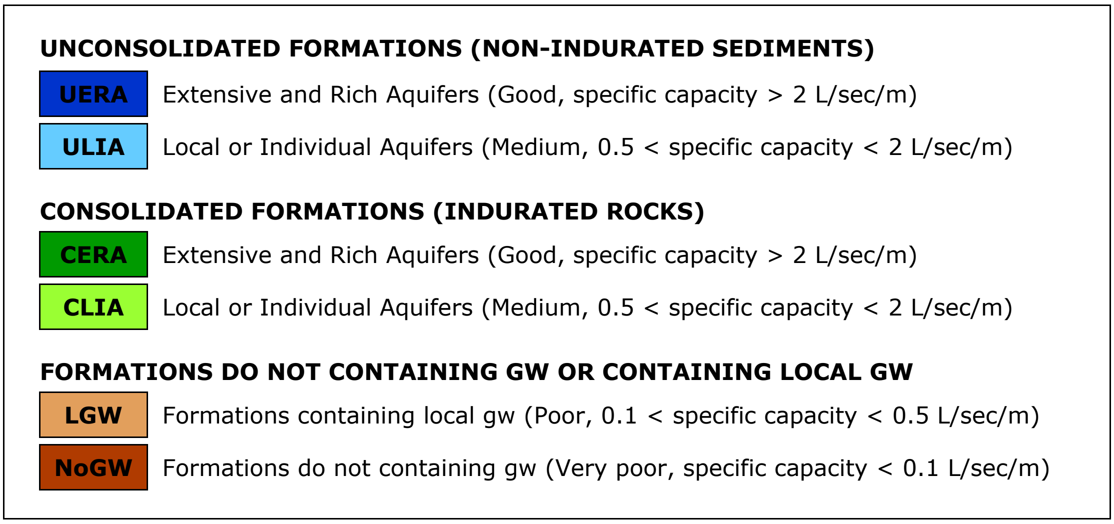
A part from the legend of the hydgeological map is given in Figure 5.9 as an example. In the map legend, the lithology of each formation is represented by special ornaments and the approximate age of the formation is depicted under stratigraphy heading. Besides, a general value for water yield in terms of specific capacity, which is defined as the ratio of pumping rate to the stabilized drawdown, is estimated and given in L/sec/m for each aquifer class. However, it should be noted that the specific capacity may vary widely even in areas with uniform lithology (Nkhoma et al. 2007). The general classification of formations in the hydrogeological map of Turkey is exhibited in Figure 5.10.



UNCONSOLIDATED FORMATIONS (NONINDURATED SEDİMENTS)

STRATİGRAFİ Stratigraphy		
	🟦	YAYGIN VE ZENGİN AKİFERLER YERALTISUYU VERİMLİLİK DERECESİ; İYİ, ÖZGÜLDEBİ > 2 lt/sn/m) Extensive and rich aquifers Degree of Groundwater productivity; Good, Specific capacity > 2 lt/sec./m
KUATERNER Quaternary	Kf	KİL, KUM, ÇAKIL Clay, sand, gravel
	🟦	MEVZİÎ VEYA İRTİBATSIZ AKİFERLER YERALTISUYU VERİMLİLİK DERECESİ;ORTA,0,5 < ÖZGÜLDEBİ < 2 lt/sn./m Local or individual aquifers Degree of Groundwater productivity;Medium,0,5 <Specific capacity< 2 lt/sec./m
KUATERNER Quaternary	Ki	KİL, KUM, ÇAKIL Clay, sand, gravel
NEOJEN Neogene	ni	KİL, KUM, ÇAKIL (Konglomera, Marn, Kalker, Kumtaşı, Tüf, Aglomera) Clay, sand, gravel (Conglomerate, Marl, Limestone, Sandstone, Tuff, Agglomerate

Figure 5.9 Legend of the Hydrogeological Map of Turkey



UNCONSOLIDATED FORMATIONS (NON-INDURATED SEDIMENTS)

UERA	Extensive and Rich Aquifers (Good, specific capacity > 2 L/sec/m)
ULIA	Local or Individual Aquifers (Medium, 0.5 < specific capacity < 2 L/sec/m)

CONSOLIDATED FORMATIONS (INDURATED ROCKS)

CERA	Extensive and Rich Aquifers (Good, specific capacity > 2 L/sec/m)
CLIA	Local or Individual Aquifers (Medium, 0.5 < specific capacity < 2 L/sec/m)

FORMATIONS DO NOT CONTAINING GW OR CONTAINING LOCAL GW

LGW	Formations containing local gw (Poor, 0.1 < specific capacity < 0.5 L/sec/m)
NoGW	Formations do not containing gw (Very poor, specific capacity < 0.1 L/sec/m)

Figure 5.10 Classification of Aquifers in the Hydrogeological Map of Turkey

5.2.1.1 Analysis of the Hydrogeological Map Covering the Study Area

By using the digitized map sheets and the aquifer classification system of the hydrogeological map, the hydrogeological map covering the study area was produced as given in Figure 5.11. This map was first analyzed in order to observe the distribution of the aquifer types within the study area.

As can be seen from Figure 5.11, Black Sea and Mediterranean Regions are mostly covered with insignificant aquifers, whereas the Central Anatolian and central parts of Aegean Region are covered with local or individual aquifers of both consolidated and unconsolidated types. With respect to the chart given in Figure 5.12, formations do not containing groundwater and formations containing limited or local (perched with small volume) groundwater resources cover the largest surface area. Formations with no groundwater and formations with small or local groundwater resources cover 35.2% and 27.8% of the total surface area, respectively. Extensive and rich aquifers of consolidated formations constitute 3.1% and local or individual aquifers of the same class constitute 19.4% of total area. Unconsolidated formations constitute the smallest surface area. 6.1% of total surface area is covered by unconsolidated extensive and rich aquifers, while 8.4% is covered by local or individual aquifers.

5.2.2 Relation of Groundwater Occurrence to Geologic Age, Major Rock Groups and Rock Types

As described in Section 5.1.4, water-bearing openings occur in the form of pores, fissures or fractures depending on the geologic age (described by stratigraphy), lithology (e.g., grain size and packing), and structure of the rocks (e.g., water-bearing openings) (Heath, 1984). In this section, the relationship between groundwater occurrence and the geologic age, major rock groups and rock types were assessed by use of the hydrogeological map of Turkey.

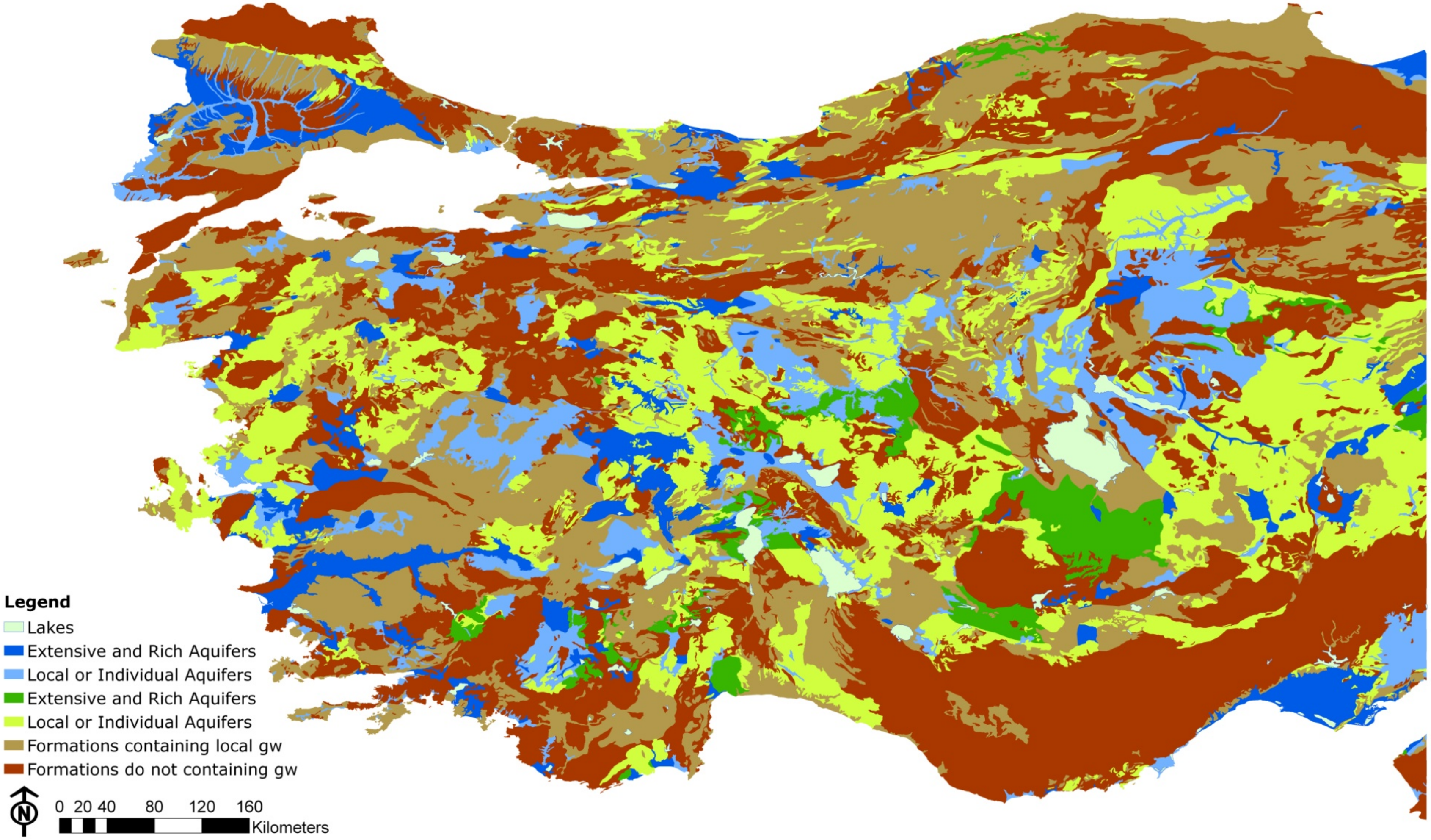


Figure 5.11 Hydrogeological Map of Turkey Covering the Study Area (Produced by Digitized Sheets)

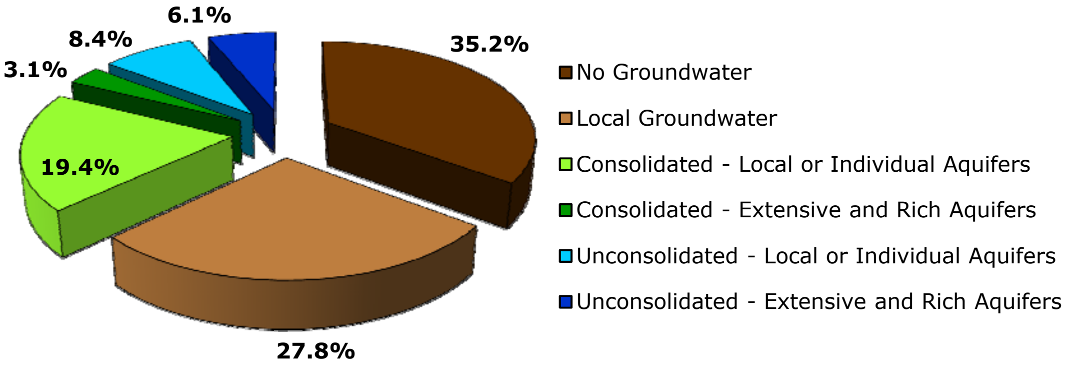


Figure 5.12 Surface Area Distributions of Formations (%)

Table 5.4 shows the relationship of water-bearing openings with the major rock groups and geologic age. With concern to the fact given in Table 5.4, the formations taking place in the hydrogeological map of Turkey (Figure 5.11) were put in the order of geologic age by using the map legend and given in Table 5.5. Total surface area of each formation in the study area was also calculated with respect to the aquifer classification system of hydrogeological map and presented in this table in order to designate the relation between geologic age (stratigraphy), formations (lithology) and aquifer distributions. However, geologic ages of some of the igneous and metamorphic rocks were not defined in the hydrogeological map. Therefore, these formations were classified with respect to major rock groups and presented as given in Table 5.6.

When Table 5.5 is compared with Table 5.4, the similarity of the relation between geologic ages and major rock groups takes attention. The following discussions are made with respect to Table 5.4, Table 5.5 and Table 5.6 and to explain these similarities. As can be seen from Table 5.5, unconsolidated formations such as clay, sand and gravel are observed mostly in Cenozoic age, which is also indicated by Heath (1984) in Table 5.4. Intergranular flow occurs through the pores between these deposits i.e., clay, sand and gravel and depending on the size of the pores they constitute either indurated aquifers (shown with tones of blue) or non-aquifers (shown with tones of brown). Semi-consolidated sedimentary rocks include both primary and secondary openings (i.e., fissures and fractures) (Heath, 1983). Limestone and sandstones can be examples for this group, and observed in Cenozoic, Mesozoic and Paleozoic ages (see Table 5.5). Likewise, consolidated sedimentary rocks, such as limestone, dolomite, siltstone, sandstone, shale and conglomerate are observed in Mesozoic and Paleozoic ages (see Table 5.5). In consolidated formations, groundwater flow through fissures or fractures. Aquifers of semi-consolidated and consolidated sedimentary formations are shown with tones of green and the formations that do not show aquifer properties are shown with tones of brown. Besides, it should be noted that larger volume of openings occurs in young rocks compared to older rocks of the same type (Heath, 1984), which means water-bearing capacity of young rocks is higher than old rocks that have been subjected to consolidation.

Extrusive igneous rocks are fine-grained rocks, such as andesite and basalt which contain water-bearing fissures and fractures (Heath, 1984). Aquifers of this class are represented by tones of green and non-aquifers are represented by the tones of brown (see Table 5.6). Whereas, intrusive igneous rocks, such as granite, diorite, gabbro have coarse-grained texture and because of this property they do not contain sufficient amounts of water-bearing openings (Heath, 1984). Intrusive igneous rocks can serve as a groundwater supply, only if water-bearing fractures occur (Heath, 1984). Low water-bearing capacity of intrusive igneous rocks can also be seen from Table 5.6, as they are mostly shown with dark brown.

Similarly, metamorphic rocks, such as marble, schist, and quartzite are among the oldest rocks, and found at Paleozoic age (see Table 5.5). The fractures in these rocks may serve as a groundwater supply, however, formations having aquifer properties are very rare in the study area (see Table 5.6).

Table 5.4. Relation of Groundwater Hydrology with Geologic Age and Major Rock Groups (Heath, 1984)

Era	Period	Epoch	Time before present (estimated in millions of years)	Sedimentary rocks			Igneous rocks		Metamorphic rocks
				Uncon-solidated (pores)	Semiconsoli-dated (pores and fractures)	Consoli-dated (fractures)	Extrusive (pores and fractures)	Intrusive (fractures)	Igneous and sedimentary (fractures)
Cenozoic	Quaternary	Holocene		┃			┃		
		Pleistocene	2	┃			┃		
	Tertiary	Pliocene	5	┃			┃		
		Miocene	24	┃	┃		┃		
		Oligocene	38	┃	┃		┃	┃	
		Eocene	55	┃	┃		┃	┃	
		Paleocene	63	┃	┃		┃	┃	
Mesozoic	Cretaceous		138	┃	┃		┆	┃	
	Jurassic		205		┃	┃	┆	┃	
	Triassic		240		┃	┃	┆	┃	
Paleozoic	Permian		290		┃	┃	┆	┃	┆
	Pennsylvanian		330		┃	┃		┃	┆
	Mississippian		360		┃	┃		┃	┆
	Devonian		410		┃	┃		┃	┆
	Silurian		435		┃	┃		┃	┆
	Ordovician		500		┃	┃		┆	┃
	Cambrian		570		┃	┃		┆	┃
Precambrian								┆	┃

Table 5.5 Classification of Rocks in the Study Area according to their Geologic Ages

ERA-PERIOD	MAPPING NOTATION	STRATIGRAPHY	FORMATION	TOTAL SURFACE AREA (km^2)					
				NoGW	LGW	CLIA	CERA	ULIA	UERA
CENOZOIC Quaternary	K3	Quaternary	Terrace	38		26			
	K2	Quaternary	Travertine	28	307	407	547		
	K1	Quaternary	Clay / Clay, sand, gravel	5322	11589			17364	17994
	plK1	Plio-Quaternary	Clay / Clay, sand, gravel (Sandstone, conglomerate, marl, limestone)	5917	1108			391	151
Tertiary Neogene	n3	Neogene	Conglomerate / Conglomerate (Clay, sand, gravel, marl, limestone)	348	611	243	102		
	n2	Neogene	Limestone / Limestone-Marl (Clay, sand, gravel, sandstone, tuff, tuffit, conglomerate, agglomerate)	4148	6347	15893	3642		
	n1	Neogene	Clay / Clay, sand, gravel (Conglomerate, marl, limestone, sandstone, tuff, agglomerate)	3305	7094			13297	4647
	n	Neogene	Clay, sand, gravel	14	100			152	
	nv	Neogene	Volcanic facies	22	698	12385			
	pl5	Pliocene	Sand						3306
	pl4	Pliocene	Clay	2018					
	pl3	Pliocene	Limestone /Limestone-Marl (Clay, sandstone, conglomerate)	1808	48	1774	5148		
	pl2	Pliocene	Conglomerate (Marl, claystone)	24		265	9		
	pl1	Pliocene	Clay, sand, gravel (Sandstone, conglomerate, marl, limestone)	456	8985			1542	563
	m5	Miocene	Clay-Marl-Sandstone (Breccia, limestone)	809		330			
	m4	Miocene	Conglomerate (Clay, sandstone, marl)	88	56	2332	311		
	m2	Miocene	Limestone (Conglomerate, sandstone, marl, clay, silexite)	570	624	195	41		
	m1	Miocene	Clay, sand, gravel		2683				
	mü1	Upper Miocene	Clay, sand, gravel (Marl, sandstone)	357	262			162	
	mo3	Middle Miocene	Clay, sand, gravel					284	
	mo1	Middle Miocene	Limestone-Marl (Sandstone, conglomerate)	3485	59	11			
	ma1	Lower Miocene	Limestone-Marl (Clay, sandstone, conglomerate)	10823					

Table 5.5 Classification of Rocks in the Study Area according to their Geologic Ages (cont'd)

ERA-PERIOD	MAPPING NOTATION	STRATIGRAPHY	FORMATION	TOTAL SURFACE AREA (km^2)					
				NoGW	LGW	CLIA	CERA	ULIA	UERA
CENOZOIC Tertiary Paleogene	olm4	Oligo-Miocene	Claystone-Gypsiferous facies			3715			
	olm3	Oligo-Miocene	Sandstone-Gypsiferous facies				474		
	olm2	Oligo-Miocene	Clay, sand, gravel-Gypsiferous facies	487	618			3571	23
	olm1	Oligo-Miocene	Limestone /Limestone -Marl (Conglomerate, sandstone, andesitelave alternation)		524				
	ol4	Oligocene	Sandstone - Peat	46					
	ol3	Oligocene	Sandstone - Gypsiferous facies	99					
	ol2	Oligocene	Limestone-Marl (Clay, sandstone, conglomerate) / Gypsiferous Facies	391	27	81			
	ol1	Oligocene	Limestone-Marl	138	85		403		
	olf	Oligocene	Flysch	1173					
	eol2	Eocene-Oligocene	Conglomerate / Sandstone-Conglomerate	560	1543	891			
	eol1	Eocene-Oligocene	Limestone-Marl (Clay, sandstone, conglomerate)		268				
	eolf	Eocene-Oligocene	Flysch	864					
	e3	Eocene	Sandstone - Conglomerate	15					
	e2	Eocene	Conglomerate		34				
	e1	Eocene	Limestone (Marl, shale, sandstone, conglomerate)	790	98	555			
	e	Eocene	Limestone	20		21			
	ef	Eocene	Flysch	6371	7136	2725			
	ev	Eocene	Volcanic facies	611	2954	997			
	eü2	Upper Eocene	Peat	107					
	eü1	Upper Eocene	Limestone (Marl)	248					
	el2	Middle Eocene-Lutetian	Conglomerate	119					
	el1	Middle Eocene-Lutetian	Limestone (Marl)	117	391	817	700		
	ep1	Lower Eocene-Paleogene	Marl /Limestone-Marl (Sandstone, clay, conglomerate, sand, gravel, shale)	349	2106	353			

Table 5.5 Classification of Rocks in the Study Area according to their Geologic Ages (cont'd)

ERA-PERIOD	MAPPING NOTATION	STRATIGRAPHY	FORMATION	TOTAL SURFACE AREA (km^2)					
				NoGW	LGW	CLIA	CERA	ULIA	UERA
MESOZOIC Cretaceous	MT1	Mesozoic-Tertiary	Limestone	5748	4855	903	1548		
	Mof	Mesozoic	Ophiolitic series	11623					
	Mof1	Mesozoic	Ophiolitic series (Mainly radiolorites and hornsteins)	3201		2			
	M1	Mesozoic	Mainly limestone	291	49				
	krep1	Upper Cretaceous-Paleogene	Limestone-Marl (Clay, sandstone)	316	632	128			
	kr1	Cretaceous	Limestone / Limestone-Marl	244	269	2106			
	krf	Cretaceous	Flysch	719	4531	331			
	krü2	Upper Cretaceous	Limestone / Limestone-Marl (Sandstone, conglomerate, clay, occasionally with ophiolites and paleocene)	1641	5081	5413	10		
	krü1	Upper Cretaceous	Sandstone-conglomerate	3		16			
	krüf	Upper Cretaceous	Flysch	2989	6697				
	krüv	Upper Cretaceous	Volcanic facies	441	425				
	kra1	Lower Cretaceous	Limestone (Marl)	11	289	933			
Jurassic	jkr1	Jurassic-Cretaceous	Limestone (Marl)	3345	1979	1940	552		
	jkr	Jurassic-Cretaceous	Limestone	17		20			
	j1	Jurassic	Limestone (Marl)	179	449	167			
	jv	Jurassic	Volcanic facies		133				
	jm1	Jurassic-Malm	Limestone (Marl)	3	7	64	51		
	jdm1	Jurassic-Dogger-Malm	Limestone (Marl)	38	454	55			
	jl2	Jurassic-Lias	Limestone	6	4				
	jl1	Jurassic-Lias	Limestone (Marl, sandstone)	199	69	157	23		
	jlf	Jurassic-Lias	Flysch	1180					
Triassic	t3	Triassic	Limestone	284					
	t2	Triassic	Sandstone-conglomerate	612	2				
	t1	Triassic	Limestone (Marl) / Limestone-Marl	24	53				

Table 5.5 Classification of Rocks in the Study Area according to their Geologic Ages (cont'd)

ERA-PERIOD		MAPPING NOTATION	STRATIGRAPHY	FORMATION	TOTAL SURFACE AREA (km^2)					
					NoGW	LGW	CLIA	CERA	ULIA	UERA
PALEOZOIC	Permian	pM2	Permian-Mesozoic	Limestone	417					
		pM1	Permian-Mesozoic	Limestone / Limestone (Crystalline limestone, marl, schist, graywacke, sandstone)	1648	2806	5807			
		pM	Permian-Mesozoic	Limestone	152	42				
		p1	Permian	Limestone (Schist, crystalline limestone graywacke)	16	3				
		Pof	Paleozoic	Ophiolitic series	220					
		P2	Paleozoic	Schist Quartzite	2257	388				
		P1	Paleozoic	Limestone (Marble, crystalline limestone) / Limestone (Schist, crystalline limestone)	2388	1169	333			
		P	Paleozoic	Limestone	7	13				
		Pcr	Paleozoic	Metamorphic series	12737	92	190			
	Carboniferous	pk1	Permo-Carboniferous	Limestone (Sandstone, schist)	1615	277	1078			
		k2	Carboniferous	Clay, Clayey-loamy alteration products	45					
		k1	Carboniferous	Limestone	86					
	Devonian	d2	Devonian	Marble, schist / Schist (Quartzite, marble)	3116	192				
		d1	Devonian	Limestone (Sandstone, schist, conglomerate, graywacke, arkose, shale, quartzite)	301	543				
	Silurian	sd2	Silurian-Devonian	Schist-Quartzite (Sandstone, conglomerate)	1029					
		sd1	Silurian-Devonian	Limestone	33	215				
		s4	Silurian	Sandstone-Conglomerate-Quartzite	663					
		s3	Silurian	Schist	1292					
		s2	Silurian	Sandstone, quartzite	6					

Table 5.6 The Other Igneous and Metamorphic Rocks Observed in the Study Area

ROCK TYPE	**MAPPING NOTATION**	**ROCK TYPE**	**TOTAL SURFACE AREA (km^2)**					
			NoGW	**LGW**	**CLIA**	**CERA**	**ULIA**	**UERA**
Extrusive Igneous Rocks	alpha	Andesite, spilite, porphyrite	632	15599	9165			
	alpha_K	Andesite, spilite, porphyrite		192				
	alpha_T	Andesite, spilite, prophyrite	629					
	alpha_epsilon_tau	Volcanic rocks			612			
	alpha_lambda	Andesite, rhyolite	97		902			
	alpha_tau	Andesite, trachyte		26				
	beta_alpha	Andesite, basalt		216	324			
	beta	Basalt, dolerite	121	1206	611			
	epsilon	Volcanic rocks			182			
	epsilon_tau	Volcanic tuff, agglomerate, breccia	21	2122	4273			
	tau	Trachyte, phonolite	11	8				
	lambda	Rhyolite, dacite	72	176	687			
Intrusive Igneous Rocks	pi	Acid intrusives	342					
	gamma_phi	Granite, syenite	17					
	gamma	Granite, grano-diorite, quartz-diorite	8496					
	phi	Syenite, monzonite	187					
	omega	Basic intrusives	268					
	delta	Diorite, gabbro, diabase	861					
	rho	Peridotite, pyroxenite, harzburgite	312					
	s	Serpentine	1510					
	delta_s	Diorite, serpentine	71					
	rho_delta	Peridotite, diorite	747					
	rho_omega	Peridotite, basic intrusives	329					
	rho_omega_s	Peridotite, serpentine, basic intrusives	432					
	rho_s	Peridotite, serpentine	4771		131			
	s_rho_delta	Serpentine, peridotite, diorite	3313					
Metamorphic Rocks	Cr	Metamorphic series	13133	8422	141			
	Mr	Marble, crystalline limestone, dolomite	942	1457	3891			
	G	Gneiss, micaschist, amphibolite	2638	3544				
	Q	Quartzite	200					

5.2.2.1 Geologic Age and Major Rock Groups

To differentiate rocks according to their water-bearing capacities and to see the distribution of these rocks within the country, Heath's (1984) approach was utilized. The formations were grouped first according to major rock groups as sedimentary rocks, igneous rocks and metamorphic rocks, which have different water-bearing properties. Then, sedimentary rocks were sub-grouped with respect to their geologic ages (i.e., Cenozoic, Mesozoic and Paleozoic ages), which determine their consolidation condition, and thus their water-bearing capacity. As described in Section 5.1.4, younger sedimentary rocks tend to have larger volume of openings compared to older ones which had been subjected to consolidation. On the other hand, igneous rocks were further classified as extrusive and intrusive igneous rocks. Because fine-grained extrusive rocks tend to hold more groundwater compared to coarse grained intrusive igneous rocks (described in Section 5.1.4). However, metamorphic rocks were not classified further, because fractures in these rocks are the only mechanism that determines their water-bearing capacity. As a result of this classification, six groups were obtained, surface area distribution for which are exhibited in Figure 5.13. The areal distribution of these groups at different parts of the study area is also shown in Figure 5.14. The following discussions are based on these two figures.

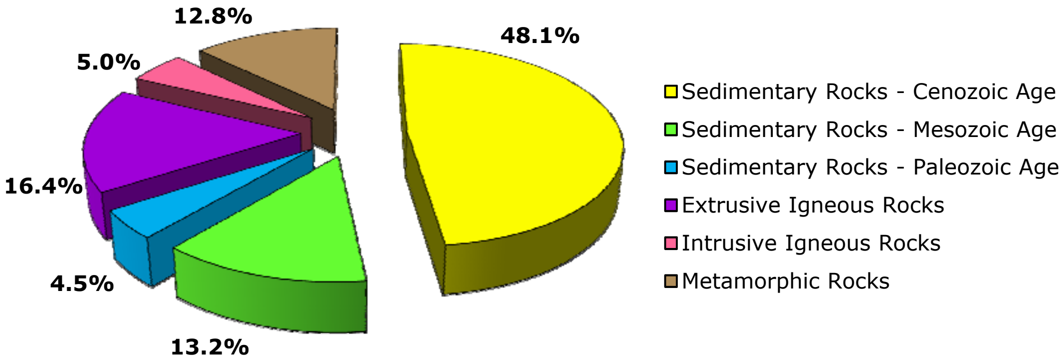


Figure 5.13 Surface Area Distributions of Major Rock Groups in the Study Area

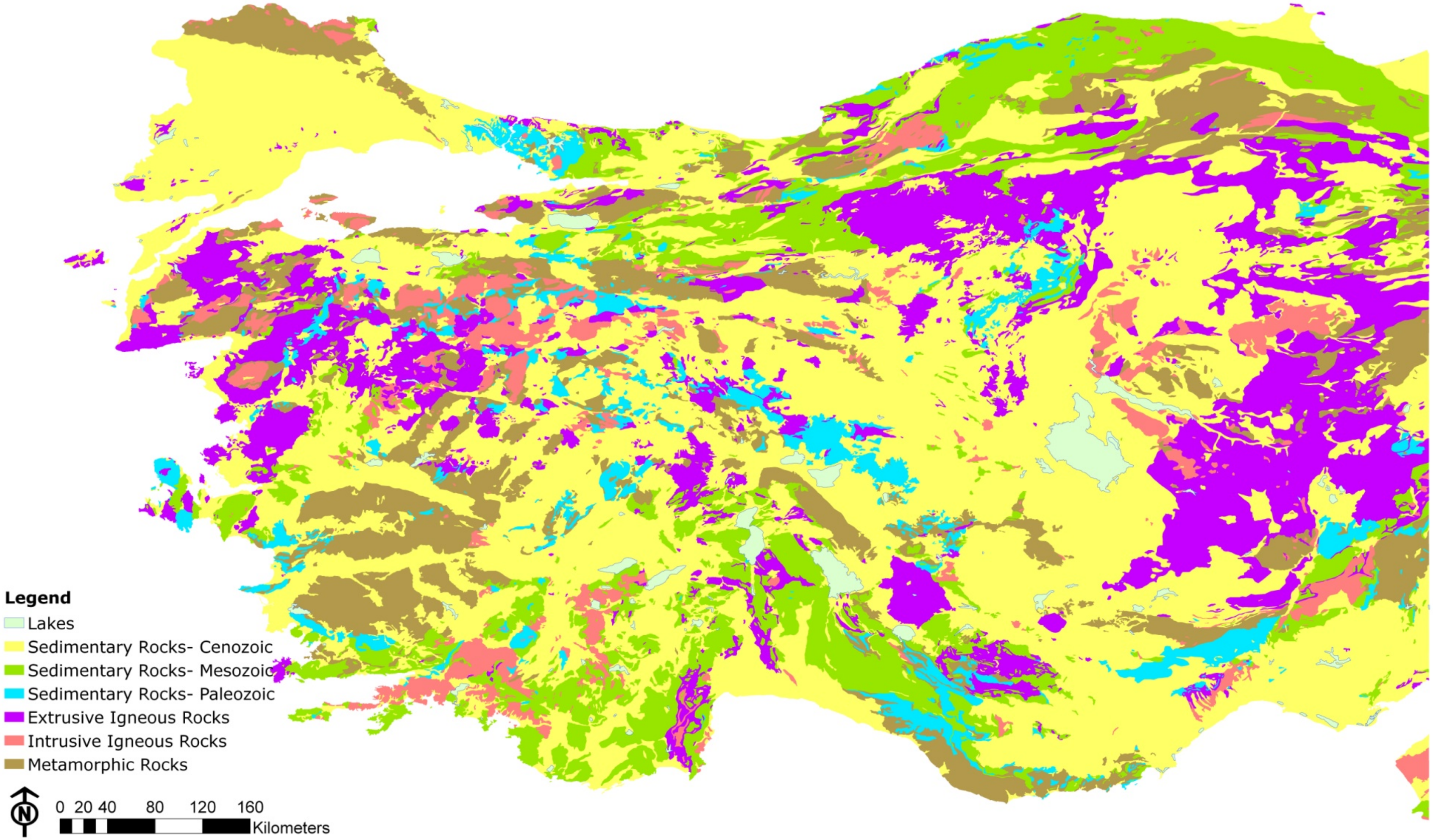


Figure 5.14 Geologic Age of Major Rock Groups in Turkey

The study area is dominated by sedimentary rocks with a total percentage of 68.5. Sedimentary rocks of Cenozoic age could be observed mostly at Thrace, Central Anatolia, and East Mediterranean Regions, and partly at South Aegean Region. At Black Sea Region, sedimentary rocks of Mesozoic age dominate and these types of rocks could also be observed at Western Mediterranean Region. Sedimentary rocks of Paleozoic age are not observed frequently amongst the overlying strata. They are distributed over the Anatolia and constitute 4.5% of the study area. Extrusive and intrusive igneous rocks cover 21.4% of the total surface area. Extrusive igneous rocks occupy 16.4% and found mostly at northern and eastern parts of Central Anatolia Region, and northern Aegean Region. Metamorphic rocks cover 12.8% of the total surface area and found in patches at Thrace, central part of Black Sea and South Aegean Regions.

5.2.2.1 Water-Bearing Rock Types

Another important property that determines the water-bearing capacity of rocks is the *lithology* which describes the physical make-up (mineral composition), grain size, and grain packing. The rocks important in groundwater hydrology are presented in Table 5.7. The rock types that are able to hold large amounts of groundwater are sand and gravel, limestone and dolomite, basalt, and sandstone (Heath, 1984). Rocks such as conglomerate, silt, siltstone, till, tillite, coquina, gneiss, quartzite, schist, slate, marble, granite and other coarse grained igneous rocks are considered to form aquitards (since they are sources of small to moderate groundwater supplies), while clay, marl, and shale are regarded as confining units of groundwater at most places (Heath, 1984).

In this regard, the occurrence of the principal water-bearing rocks in the study area was examined. The areal distribution of the rock types and the occurrence of these rocks at different parts of the study area are given in Figure 5.15 and Figure 5.16, respectively. According to these two figures, 23.5% of the study area is occupied by sand and gravel. Sand and gravel formations are considered as the important sources of groundwater due to their high water yield. This rock type is observed mostly at Marmara and the Central Anatolia Regions and partly at the East Mediterranean and Aegean Regions, especially along riversides.

Table 5.7. Rocks Important in Ground-Water Hydrology (Heath, 1984)

SEDIMENTARY ROCKS		**METAMORPHIC ROCKS**	**IGNEOUS ROCKS**	
Unconsolidated (pores)	**Consolidated (pores, fractures, and solution openings)**	**(fractures)**	**Intrusive (fractures)**	**Extrusive (pores, tubes, rubble zones, and fractures)**
GRAVEL [1]	Conglomerate [2]	Gneiss	Granite and other coarse-grained igneous rocks	BASALT and other fine-grained igneous rocks
SAND	SANDSTONE	Quartzite-schist		
Silt	Siltstone	Schist		
Clay [3]	*Shale*	Slate-schist		
Till	Tillite (rare)	Marble		
Marl	LIMESTONE-DOLOMITE			
Coquina				

[1] Capitalized names indicate rocks that are major sources of large groundwater supplies.
[2] Lower-case names indicate rocks that are sources of small to moderate groundwater supplies.
[3] Italic names indicate rocks that function primarily as confining beds.

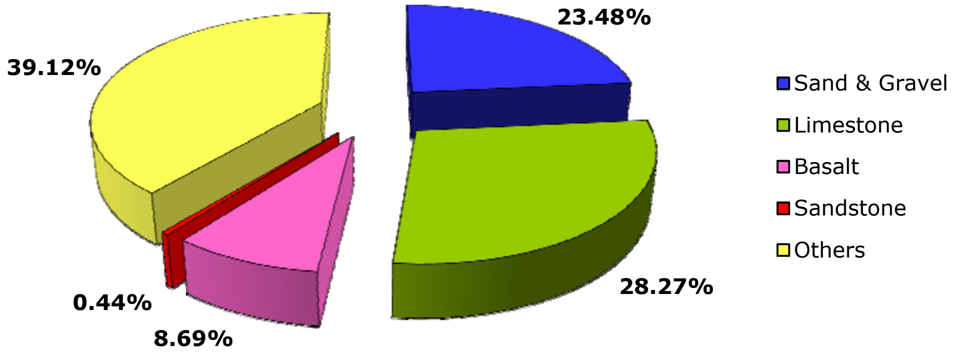


Figure 5.15 Surface Area Distributions of Principal Water-Bearing Rocks in the Study Area

Limestone occupies 28.3% of the study area. Limestone dominates Mediterranean Region and extends to the western parts of the Central Anatolia and to the eastern parts of Aegean Regions. The soluble character of limestone results in enlargement of the openings in the rock, and even in formation of large cave systems. Because of this property, limestone wells supply large yields. However, Cenozoic aged limestone formations found in the central Mediterranean Region do not supply sufficient amounts of groundwater due to geomorphologic structure of the region.

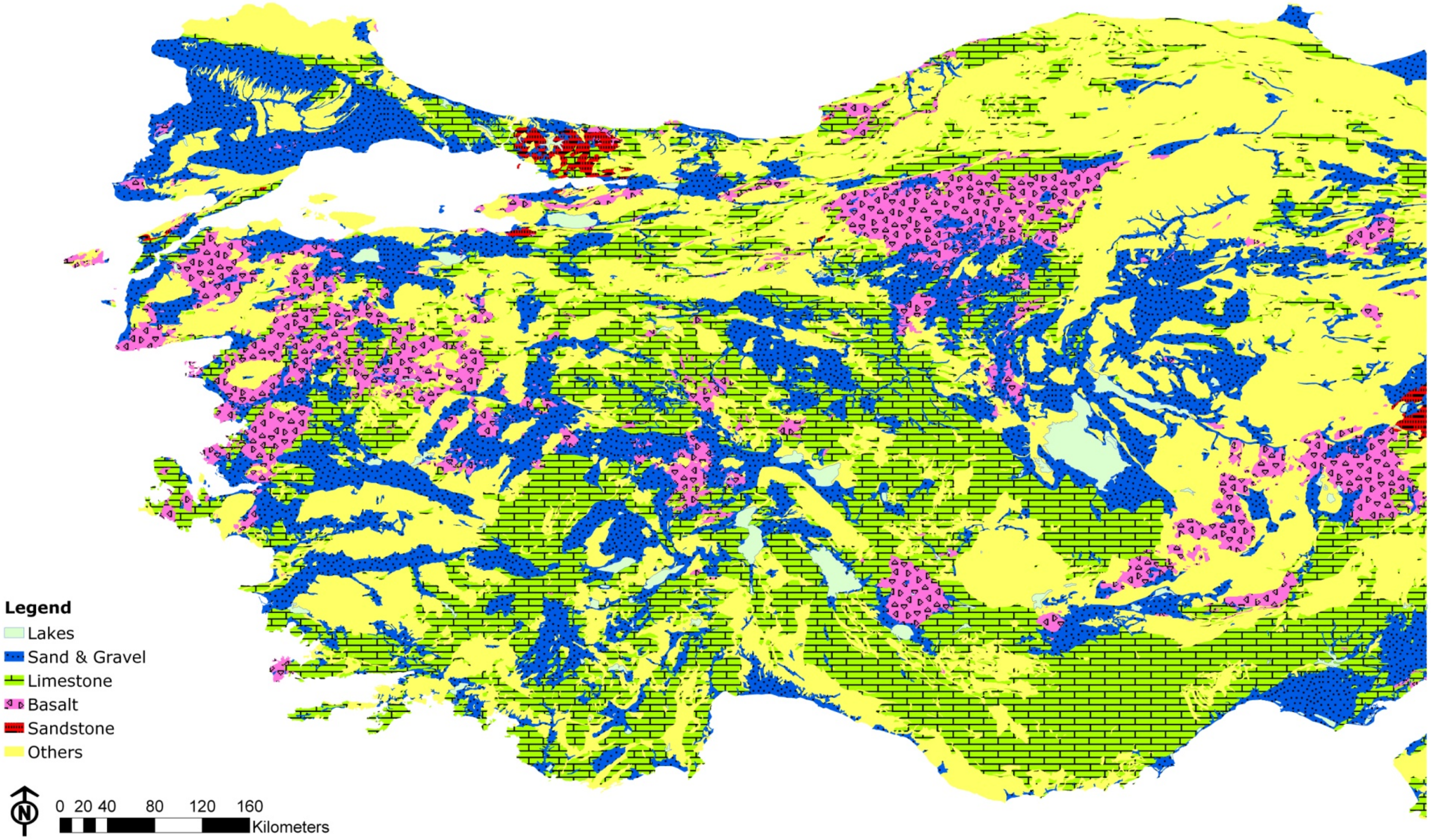


Figure 5.16 Principal Types of Water-Bearing Rocks in Turkey

Basalt and other fine-grained igneous rocks, such as andesite and rhyolite are grouped under the heading *'basalt'* and they constitute 8.7% of the study area. Basalt and other fine-grained igneous rocks are regarded amongst the important groundwater supplies. Basalt group rocks are mostly occur in the northern parts of the Central Anatolia and Aegean Regions. Sandstone, which serves as a good groundwater supply due to its fractured form, is not a widespread formation in Turkey. It only constitutes 0.44% of the study area and underlie in some parts of Marmara and Central Anatolia. The other sedimentary, igneous and metamorphic rock types, which supply small to moderate amounts of groundwater, or function as a confining bed to the aquifer, are considered to have less significance in terms of groundwater productivity and availability. These rocks are grouped under the heading of *'others'*. This group of rocks is observed almost every part of the study area and occupies 39.1%. Rocks denoted as *others* occur mostly in the Black Sea, the eastern and southern parts of Central Anatolia, and some parts of Aegean and Marmara Regions.

5.2.3 Delineation of Groundwater Regions

As mentioned by Heath (1984), the composition (lithology), arrangement (stratigraphy) and structural features (pores, fractures, folds, or faults) are important criteria to identify the presence and availability of groundwater. Therefore, these criteria are used for delineation of groundwater regions, which are in fact the rock units similar in terms of these properties. For this reason, the map of geologic age of major rock groups (Figure 5.14) and the map of water-bearing rock types (Figure 5.16) were overlapped. In this manner, the features influencing the presence and availability of groundwater could be seen together in a single map, which is exhibited in Figure 5.17.

As water-bearing rock types are classified with respect to their geologic ages, fourteen different classes are obtained (see Table 5.8), which can also be seen from the legend of the map given in Figure 5.17. For the overlying strata, *sand and gravel* is only observed at Cenozoic age. The rock types of *limestone, sandstone* and *others* are seen at Cenozoic, Mesozoic and Paleozoic ages. Basalt and other fine-grained igneous rocks (*basalt)*, and other non-water-bearing extrusive igneous rocks (*others*) are found under extrusive igneous rocks group; whereas, intrusive igneous and metamorphic rocks are all considered under *others* heading.

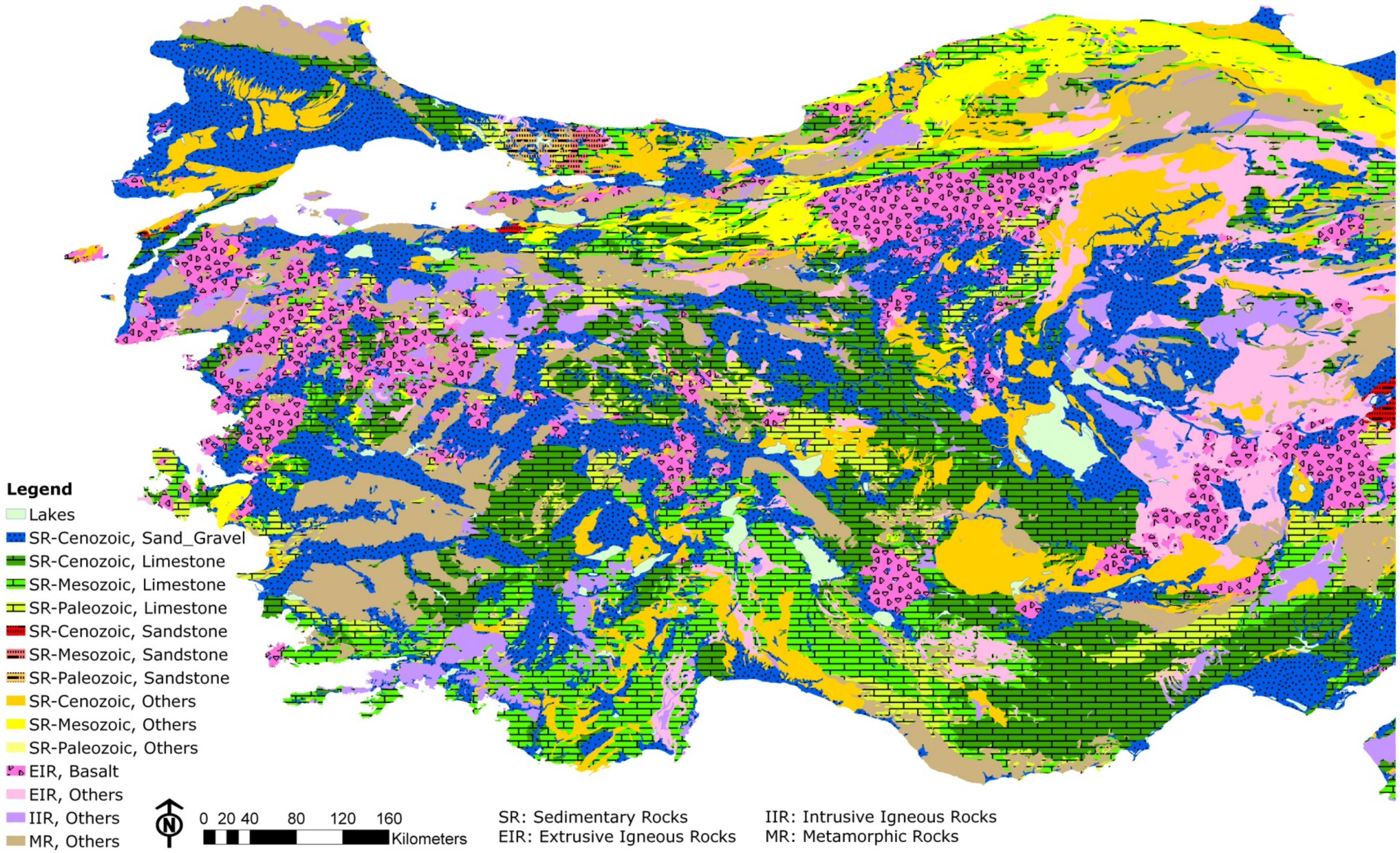


Figure 5.17 Geologic Ages of Water-Bearing Rocks in Turkey

Table 5.8 Geologic Ages and Water-Bearing Rock Types

	Sand & Gravel	Limestone	Basalt	Sandstone	Others
Sedimentary Rocks of Cenozoic Age	√	√		√	√
Sedimentary Rocks of Mesozoic Age		√		√	√
Sedimentary Rocks of Paleozoic Age		√		√	√
Extrusive Igneous Rocks			√		√
Intrusive Igneous Rocks					√
Metamorphic Rocks					√

The map given in Figure 5.17 is studied further, in order to delineate the groundwater regions at the study area. For this purpose, the map was generalized by use of the spatial analyst tools of a Geographical Information Systems (GIS) programme, ESRI software ArcInfo Workstation 9.3. The sequence of processes applied for generalization of the map by use of ArcInfo is shown in Figure 5.18. Since the vectoral analysis tools were not sufficient to make the desired generalization, first of all, the vectoral data set was converted to raster. In order to get rid of the single or isolated groups of cells *majority filter* was applied. The most frequently appearing value at the neighborhood was assigned to those single cells by this application. Following that, *region group*, which identifies the clusters having the same cell value, was applied. This function assigns a unique value to each cluster. Therefore, a LINK field was produced to keep the original cell values at the attribute table. Because some of the regions were too small to consider for delineation, the regions smaller than the defined area threshold were clarified by *extract by attributes* tool. The study performed for determination of the optimal area threshold is discussed in the following paragraphs. After extraction of negligible areas, *nibble* tool was used to reassign the best fitting values to those small regions by considering the dominating cell value in the adjacent cells. Then, *join field* function was used to reassign the original cell values located in the LINK field of the attribute table to those regions created by *region group*. Finally, the generalized map was obtained in vector format by converting the output raster layer to polygon and clipping it with the original boundary map.

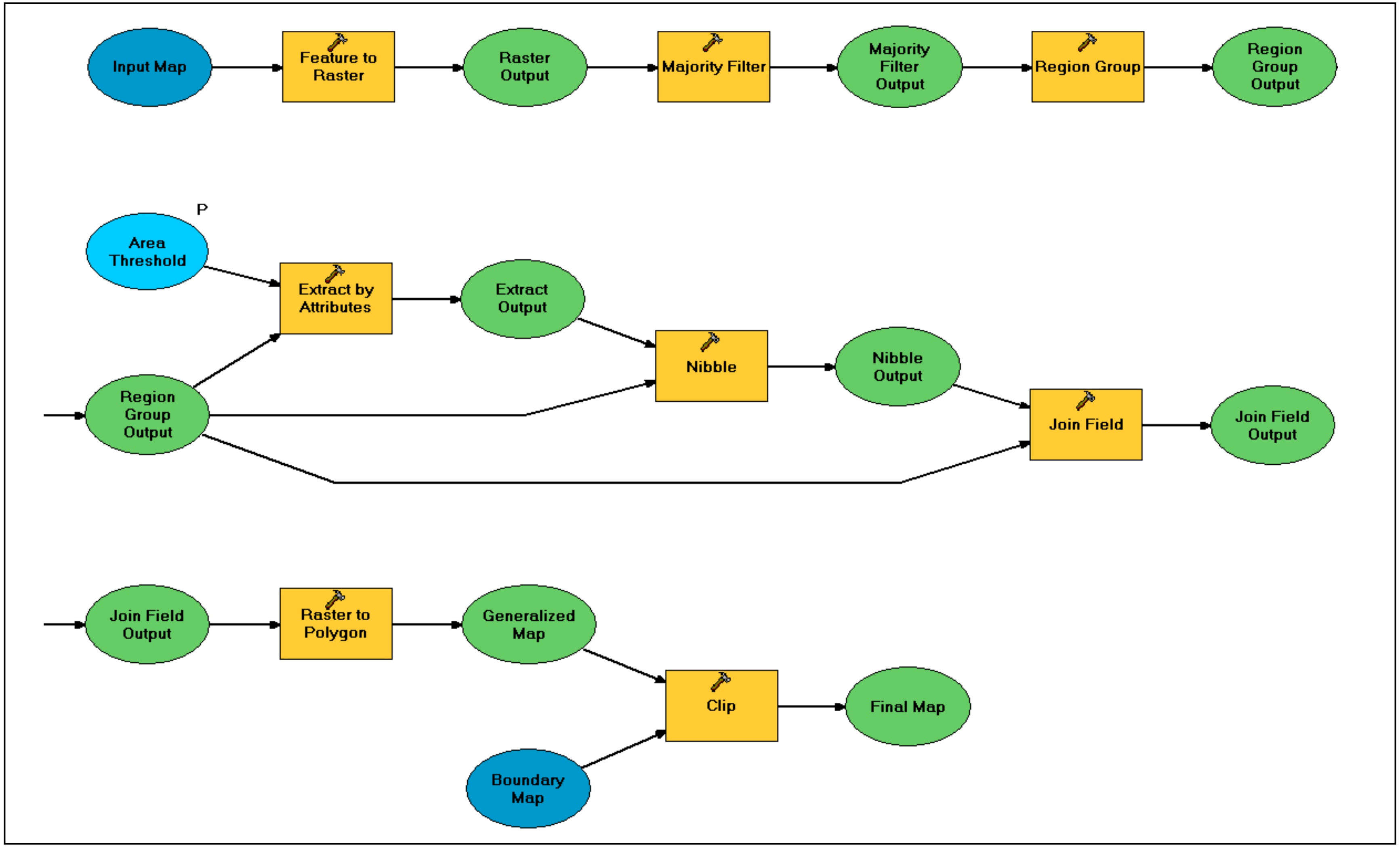


Figure 5.18 The GIS Spatial Analysis Model Used for Generalization of the Map

In order to determine an optimum area threshold, different area threshold values were tried and the deviation of the resulting map from the original map was observed. The area threshold values of 25km^2, 50km^2, 100km^2, 250km^2, 500km^2, 750km^2, and 1000km^2 were considered one by one. The best results for the generalization, which can be observed by visual analysis, were obtained for area thresholds smaller than 500km^2. Above this value, the generalization map deviates a lot from the original map which hinders the sensitivity for delineation. On the other hand, the area thresholds below 100km^2 result with the generalized maps that are very similar to the original map which makes difficult to make any regionalization. Another important factor for determination of the area threshold is the scale of the map to be produced. The area threshold selected has to be compatible with the scale of the map; likewise, the minimum mappable unit depends on the scale of the map. Higher area threshold values are suitable for small scale maps, while smaller area threshold values to be used for large scale maps. Since the groundwater regions map was decided to be produced at 1:1,500,000 scale, the areas smaller than 1cm^2, which makes 15km x 15km = 225 km^2 in real, was considered as negligible. After deciding on the area threshold to be used, the GIS spatial analysis model (shown in Figure 5.18) was used to generalize the map. As the map was generalized with respect to the fourteen classes indicated in Table 5.9, some of the classes (e.g. sandstone and others group of Paleozoic age) were disappearing due to their existence in very small percentages. Consequently, sandstone of different ages were combined and considered together in a single class. Similarly, *others* of Paleozoic age were included in *others* of Mesozoic age. This simplification resulted in eleven classes shown in Table 5.10.

The generalization procedure was applied again in order to see the compliance of the map produced with the original one. However, this classification was disturbing the integrity of limestone formations in some places. In other words, the areas dominated with limestone of different ages were being regarded by the model as different classes, and therefore, these areas were being covered by less dominant formations. Because of this reason, limestone of different ages is decided to be considered within one class. With this modification, the number of classes to be taken into account dropped to nine. The latest classification used for groundwater delineation is shown in Table 5.11.

Table 5.9 Classification of Formations for Generalization-14 Classes (Areal Distribution in %)

	Sand & Gravel	Limestone	Basalt	Sandstone	Others
Sedimentary Rocks of Cenozoic Age	23.48%	14.61%		0.15%	9.84%
Sedimentary Rocks of Mesozoic Age		9.31%		0.15%	3.77%
Sedimentary Rocks of Paleozoic Age		4.35%		0.15%	0.01%
Extrusive Igneous Rocks			8.69%		7.73%
Intrusive Igneous Rocks					5.00%
Metamorphic Rocks					12.76%

Table 5.10 Classification of Formations for Generalization - 11 Classes (Areal Distribution in %)

	Sand & Gravel	Limestone	Basalt	Sandstone	Others
Sedimentary Rocks of Cenozoic Age	23.48%	14.61%		0.44%	9.84%
Sedimentary Rocks of Mesozoic Age		9.31%			3.78%
Sedimentary Rocks of Paleozoic Age		4.35%			
Extrusive Igneous Rocks			8.69%		7.73%
Intrusive Igneous Rocks					5.00%
Metamorphic Rocks					12.76%

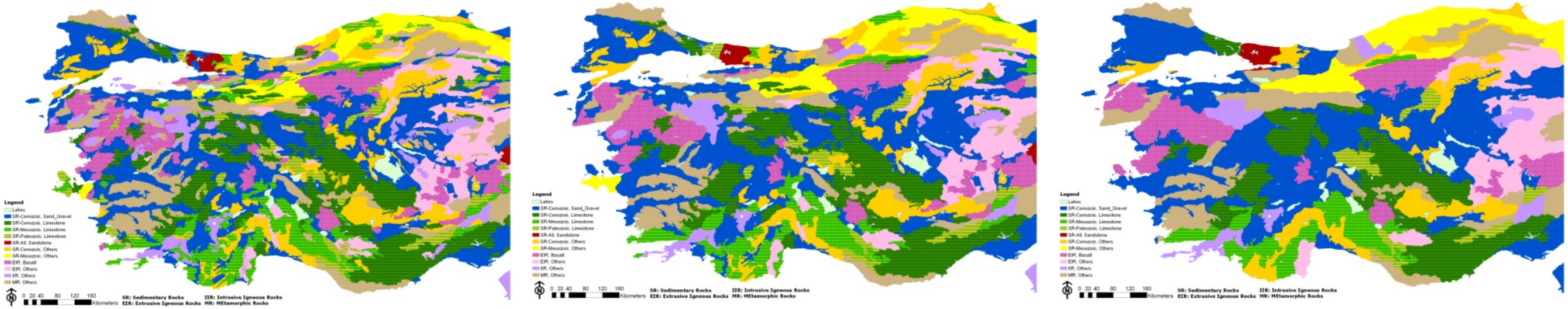
Table 5.11 Classification of Formations for Generalization - 9 Classes (Areal Distribution in %)

	Sand & Gravel	Limestone	Basalt	Sandstone	Others
Sedimentary Rocks of Cenozoic Age	23.48%	28.27%		0.44%	9.84%
Sedimentary Rocks of Mesozoic Age					3.78%
Sedimentary Rocks of Paleozoic Age					
Extrusive Igneous Rocks			8.69%		7.73%
Intrusive Igneous Rocks					5.00%
Metamorphic Rocks					12.76%

With this classification, the compatibility of the generalized map with the original map was ensured. In fact, this classification showed the superiority of water-bearing rock types (i.e., sand and gravel, limestone, basalt, sandstone) over the geologic age of major rock groups in delineation of the groundwater regions within this study area. On the other hand, geologic ages played an important role in delineation of groundwater bodies which would be described in the following sections.

Considering the above explanations, the generalized maps obtained using different area thresholds and different number of classes are presented in Figure 5.19. Among these, the generalized map produced at 225km^2 area threshold with nine classes (also given in Figure 5.20) was used for delineation of groundwater regions. In addition, the map produced at 500km^2 area threshold was also regarded as a guide to define the boundaries of some of the regions. In this process, the boundaries of regions were adjusted to achieve compatibility with the actual formation boundaries by preserving the actual formation boundaries.

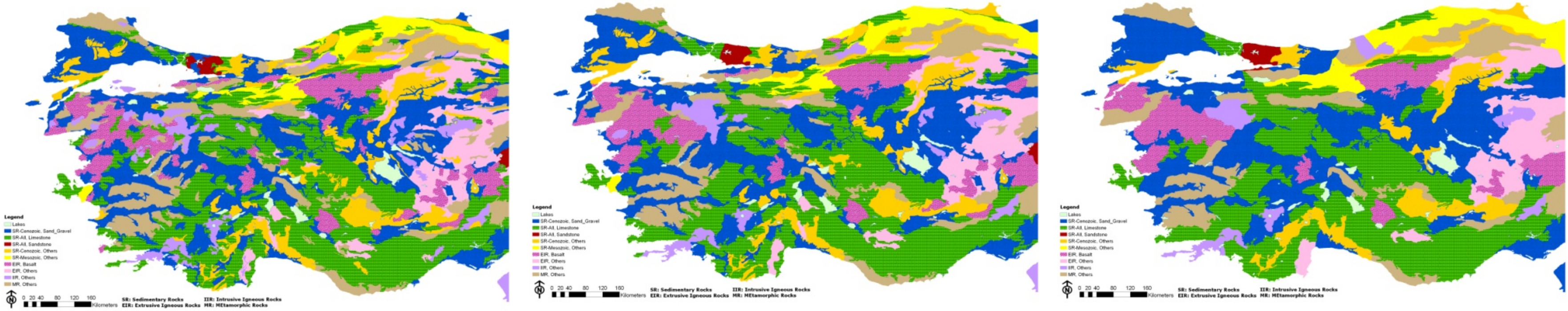
The objective of delineating the study area into groundwater regions was to classify the regions that have similar properties in terms of composition, arrangement and rock structure which designate similar conditions in occurrence and availability of groundwater. During this study, the areas representing such similarities were grouped together. As stated by Heath (1984), the nature of water-bearing openings was considered as a primary factor for dividing the regions. The contiguous formations found under the major rock groups (i.e., sedimentary rocks, igneous rocks and metamorphic rocks) were included in the same class. On the other hand, in some regions, the rocks of different origins were included in the same class due to their similar water-bearing characteristics. Some of the eastern regions that might have extensions towards the rest of the country had to be included within the boundaries of the nearest groundwater regions. Finally, the study area was delineated into thirteen groundwater regions (excluding Hatay region which has no connection to the area studied and probably would be included in some region taking part in the rest of the country) as given in Figure 5.21. In order to designate the relation of the groundwater regions delineated with geologic age and rock types, Figure 5.22 is also presented.



a) 100km^2 area threshold - 11 classes

b) 225km^2 area threshold - 11 classes

c) 500km^2 area threshold - 11 classes



d) 100km^2 area threshold - 9 classes

e) 225km^2 area threshold - 9 classes

f) 500km^2 area threshold - 9 classes

☐ Lakes
☐ SR-Cenozoic, Sand and Gravel
☐ Metamorphic Rocks, Others
☐ SR-Cenozoic, Limestone
☐ SR-Mesozoic, Limestone
☐ SR-Paleozoic, Limesone
☐ SR-Cenozoic, Others
☐ SR-Mesozoic, Others
☐ SR-Paleozoic, Others
☐ Extrusive Igneous Rocks, Basalt
☐ Extrusive Igneous Rocks, Others
☐ Intrusive Igneous Rocks, Others

Figure 5.19 Generalized Maps Produced at Different Area Thresholds with Different Number of Classes

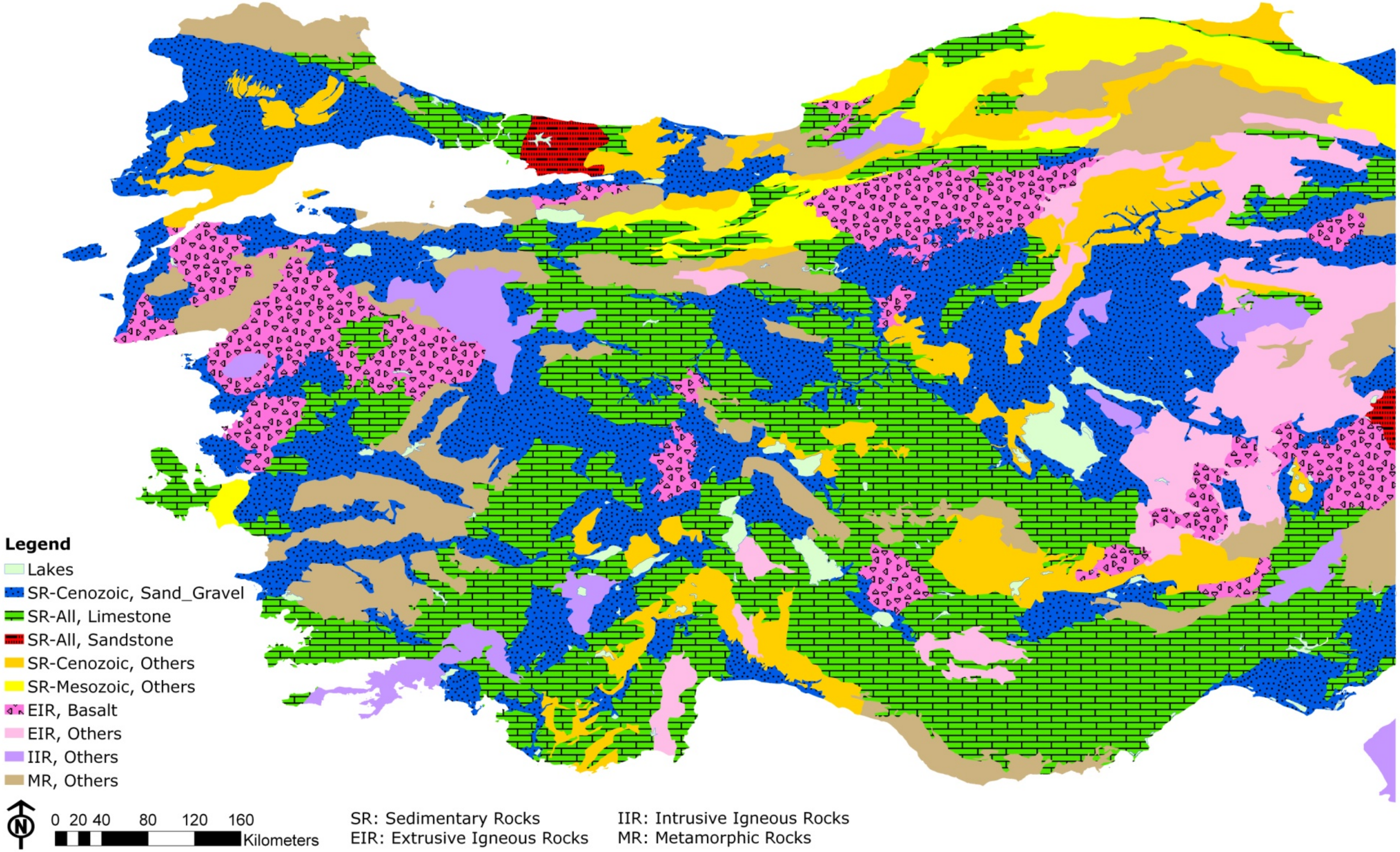


Figure 5.20 The Generalized Map Produced at 225km^2 Area Threshold with Nine Classes

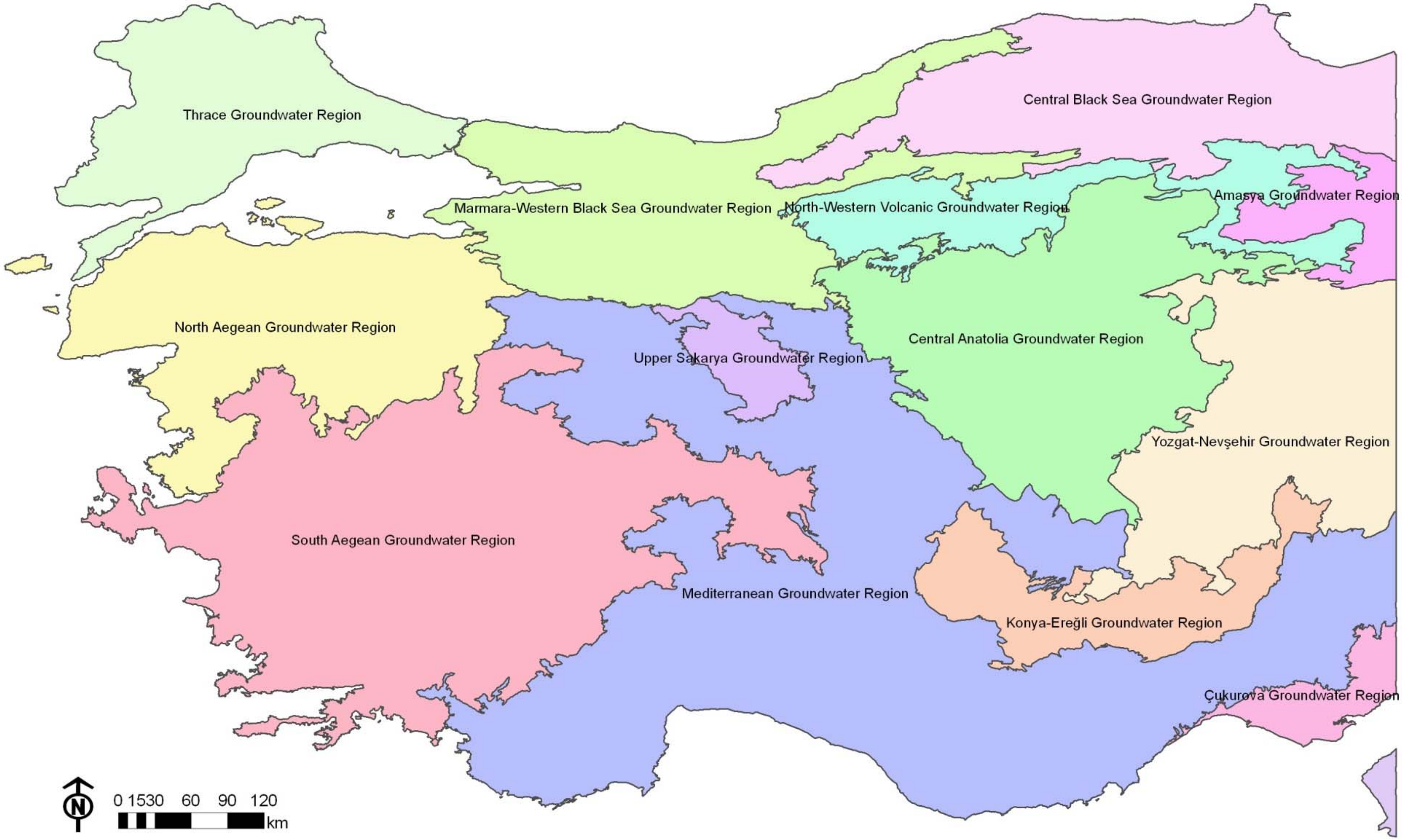


Figure 5.21 Map of Delineated Groundwater Regions

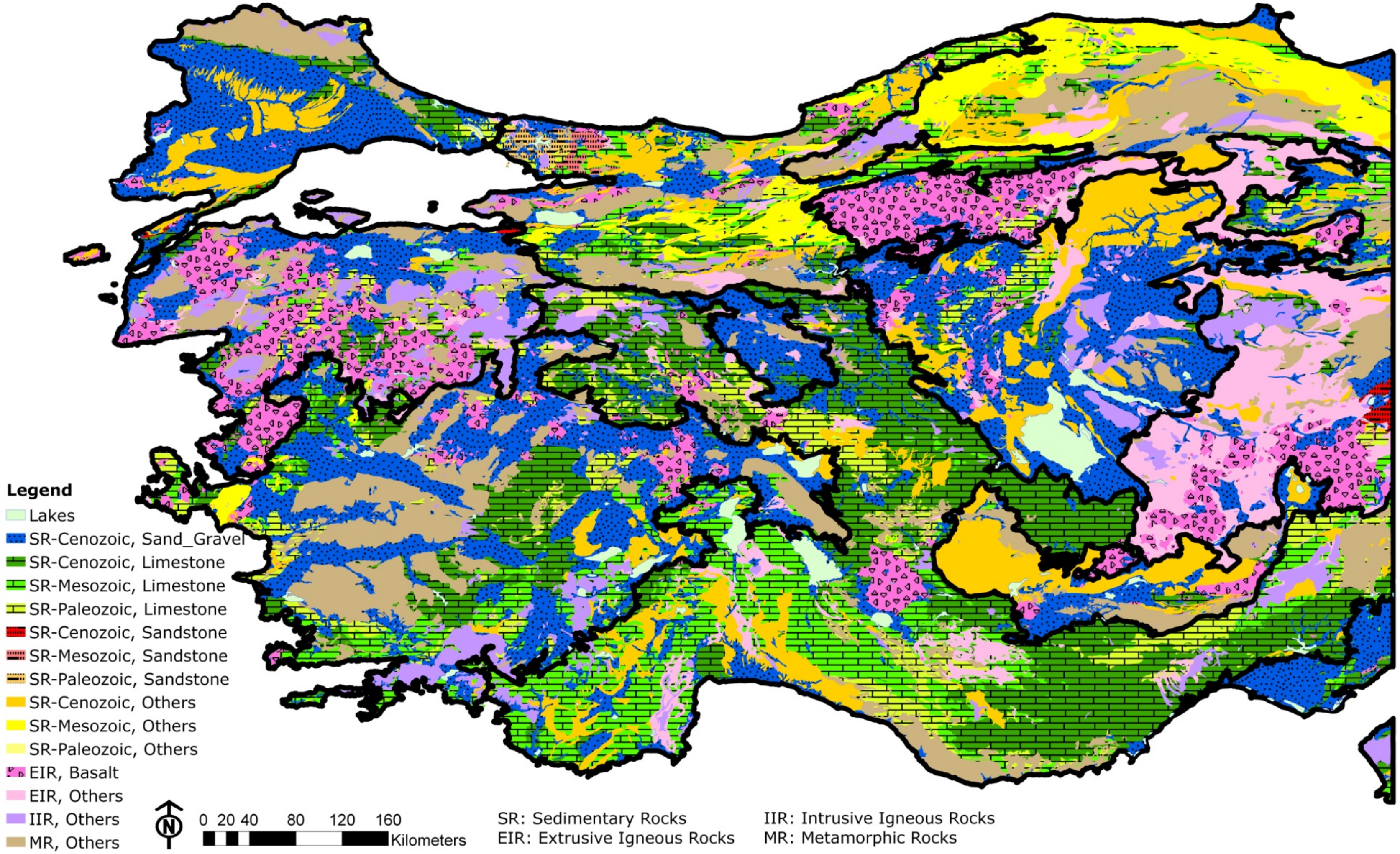


Figure 5.22 Relation of the Groundwater Regions Delineated with Major Rock Groups, Geologic Age and Rock Types

5.2.4 Delineation of Groundwater Bodies

For delineation of groundwater bodies within each groundwater region, the aquifer classification of the hydrogeological map was used, in addition to the geologic age of the major rock groups map (Figure 5.14) and the map of water-bearing rock types (Figure 5.16), which were used for delineation of groundwater regions. So that, the groundwater bodies would be delineated based on the stratigraphy, lithology and structural properties (major rock groups, geologic ages and rock types), as well as the groundwater productivity (aquifer types) of the body as mentioned by CIS (EU COM, 2004) (described in Section 5.1.3).

By combination of geologic age, rock types and groundwater availability information, Table 5.12 was produced. Combination of all these features totally resulted in forty classes given in Table 5.12, which also presents the areal distribution of each class as percentages according to their groundwater productivity. This table also points out that the water-bearing rock types, such as sand and gravel, limestone, basalt, and sandstone sometimes can be insignificant in terms of groundwater productivity. For example, the formations found under *sand and gravel* class are mostly regarded as potential sources of groundwater; however, the amount of clay type fine material in the mixture hinders the availability of groundwater. As can be seen from Figure 5.23, 38.1% of the *sand and gravel* class do not contain groundwater or contain local groundwater, while 62% have aquifer property.

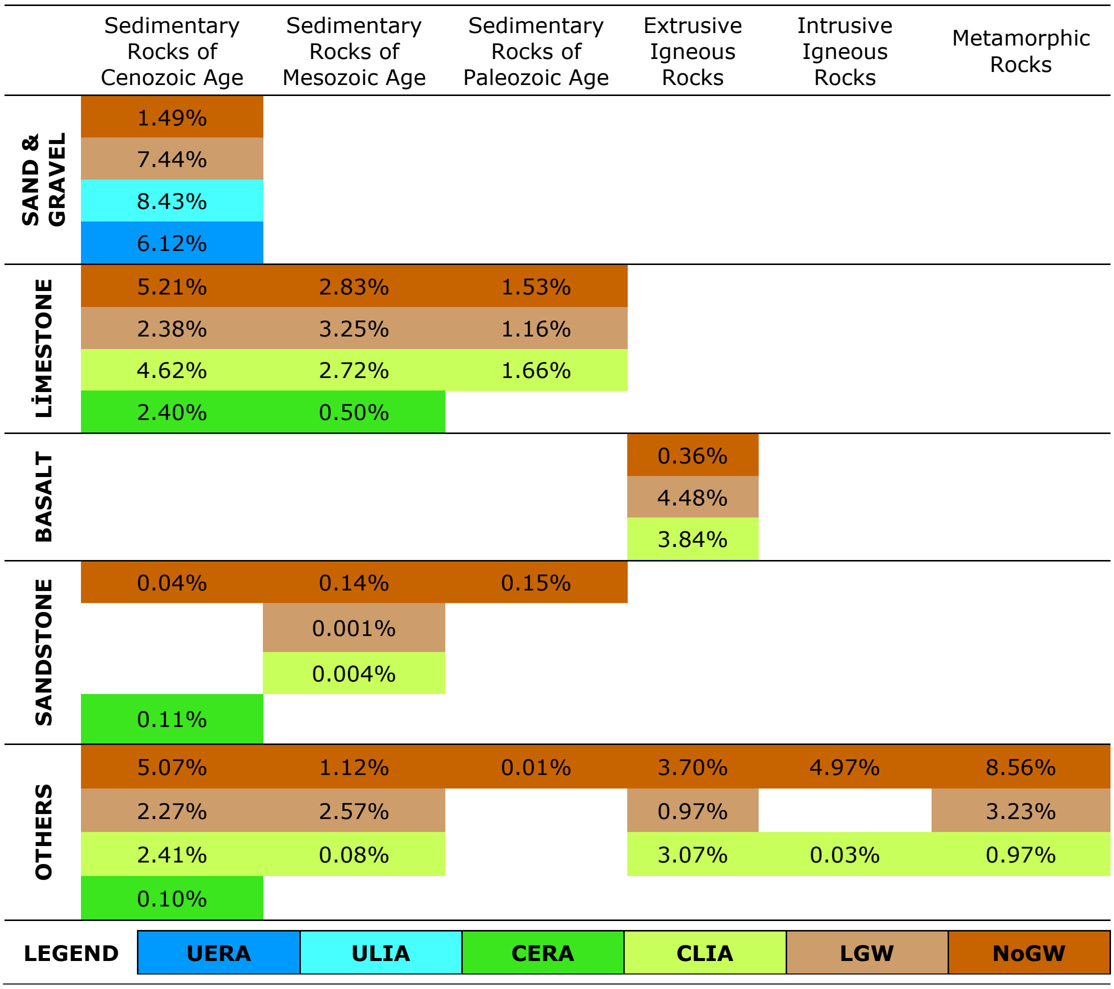
According to Figure 5.23, more than half of the formations taking place under *limestone* group do not contain groundwater or contain local groundwater. Most of the non-aquifer type limestone is found in Middle-East Mediterranean Region. On the other hand, 42.1% of the limestone serves as aquifer most of which are karstic type and located in the west of Central Anatolia Region.

44.2% of the *basalt* group formations act as local or individual aquifers (mostly found around Balıkesir and northern parts of İzmir) and 51.6% contain local groundwater. Only 4.2% of this is group is unproductive. This indicates once more that basalt type fine grained extrusive igneous rocks maintain aquifer property.

Sandstone is not an extensive formation in the study area. 74.6% of this group does not supply groundwater; however, 24.5% of the group, which makes 474km^2, contains extensive and rich aquifers and the formation is found at Kayseri province as complete.

As expected, most of the *others* class (83%) does not contain groundwater or contain local groundwater. On the contrary, 17% found around Çorum-Çankırı and Antalya provinces has aquifer property.

Table 5.12 Classification of Formations with respect to Geologic Age, Rock Type, and Aquifer Classification (Areal Distribution in %)



		Sedimentary Rocks of Cenozoic Age	Sedimentary Rocks of Mesozoic Age	Sedimentary Rocks of Paleozoic Age	Extrusive Igneous Rocks	Intrusive Igneous Rocks	Metamorphic Rocks
SAND & GRAVEL	NoGW	1.49%					
	LGW	7.44%					
	ULIA	8.43%					
	UERA	6.12%					
LİMESTONE	NoGW	5.21%	2.83%	1.53%			
	LGW	2.38%	3.25%	1.16%			
	CLIA	4.62%	2.72%	1.66%			
	CERA	2.40%	0.50%				
BASALT	NoGW				0.36%		
	LGW				4.48%		
	CLIA				3.84%		
SANDSTONE	NoGW	0.04%	0.14%	0.15%			
	LGW		0.001%				
	CLIA		0.004%				
	CERA	0.11%					
OTHERS	NoGW	5.07%	1.12%	0.01%	3.70%	4.97%	8.56%
	LGW	2.27%	2.57%		0.97%		3.23%
	CLIA	2.41%	0.08%		3.07%	0.03%	0.97%
	CERA	0.10%					

LEGEND	**UERA**	**ULIA**	**CERA**	**CLIA**	**LGW**	**NoGW**

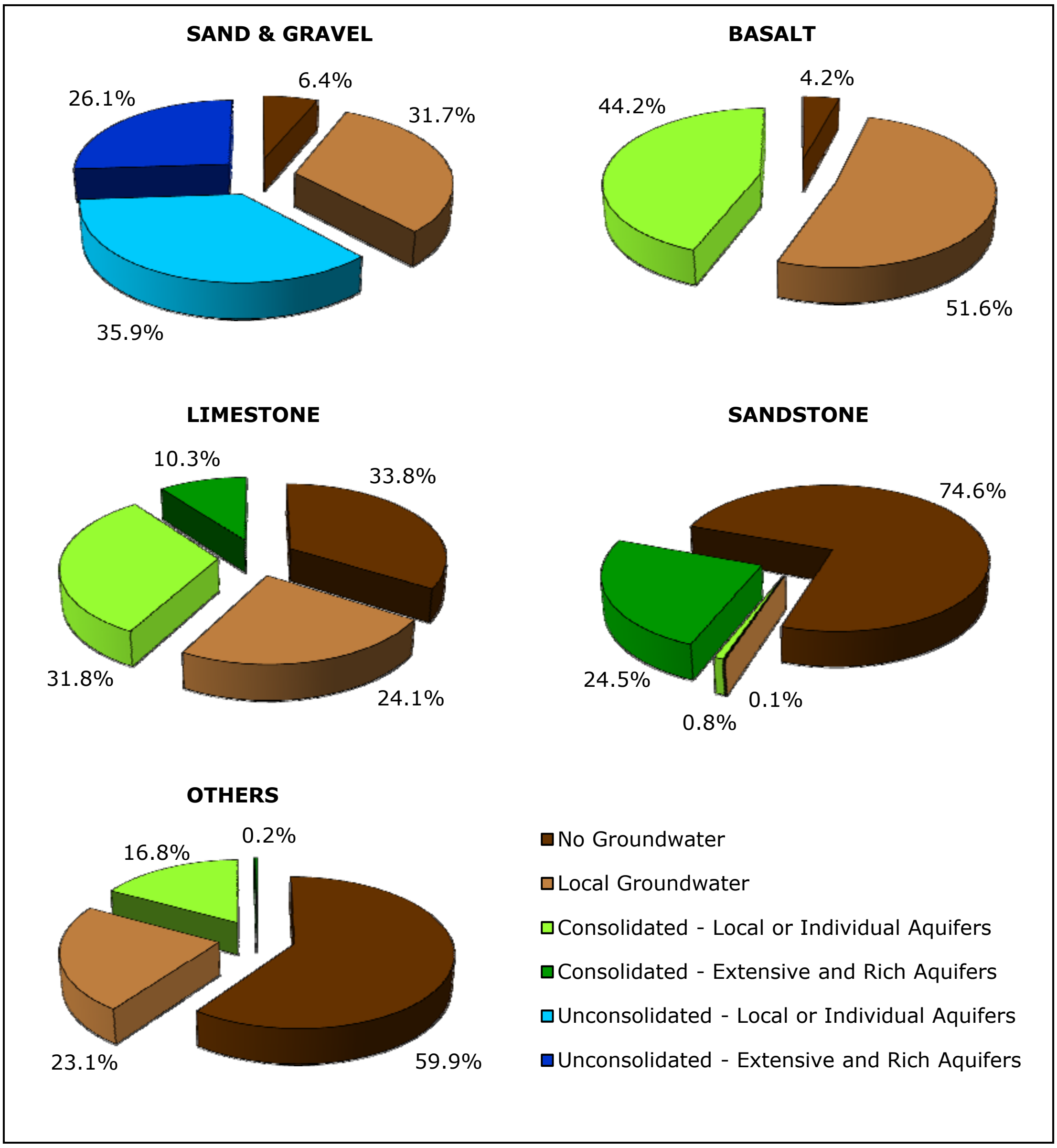
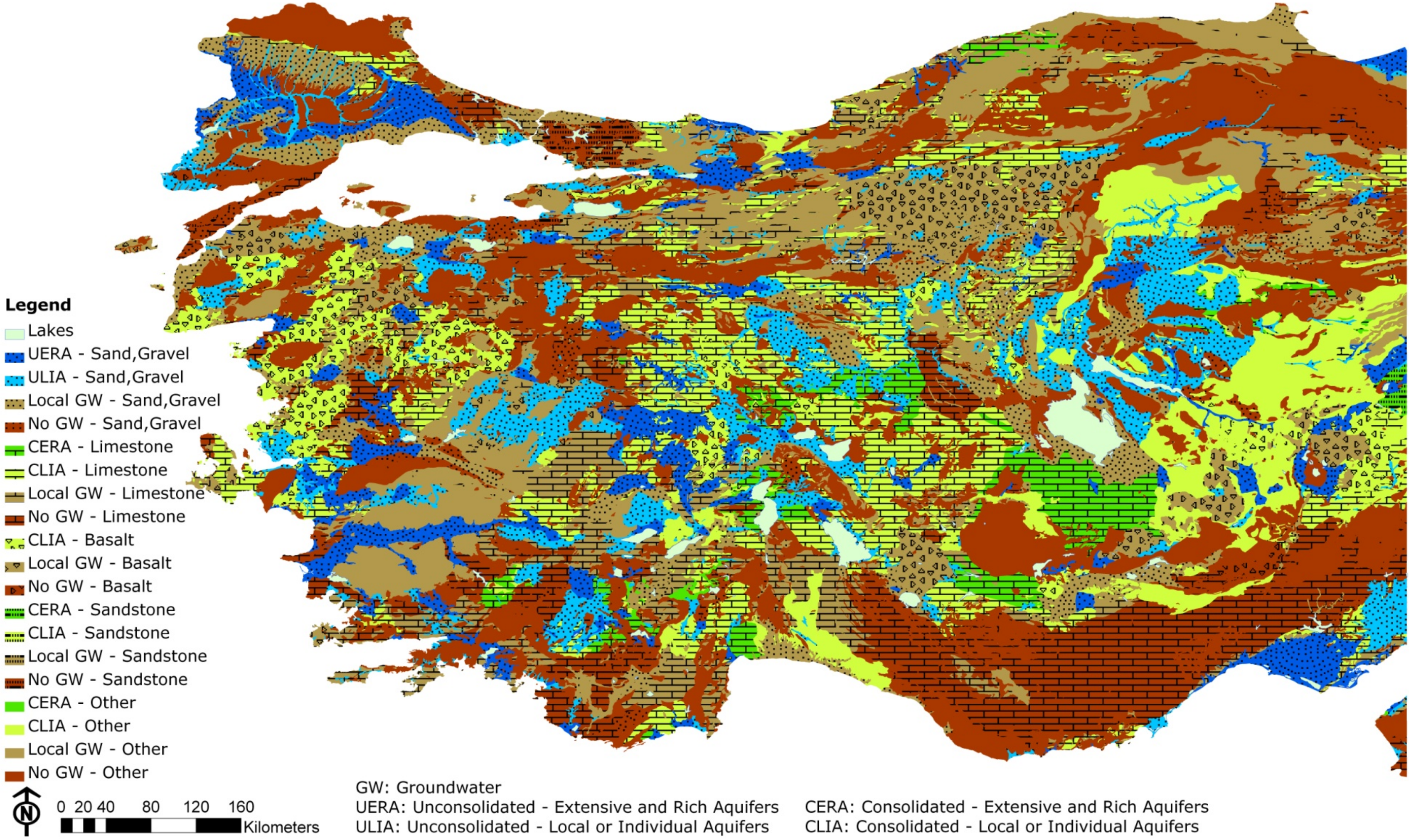


Figure 5.23 Groundwater Productivities of Rock Types



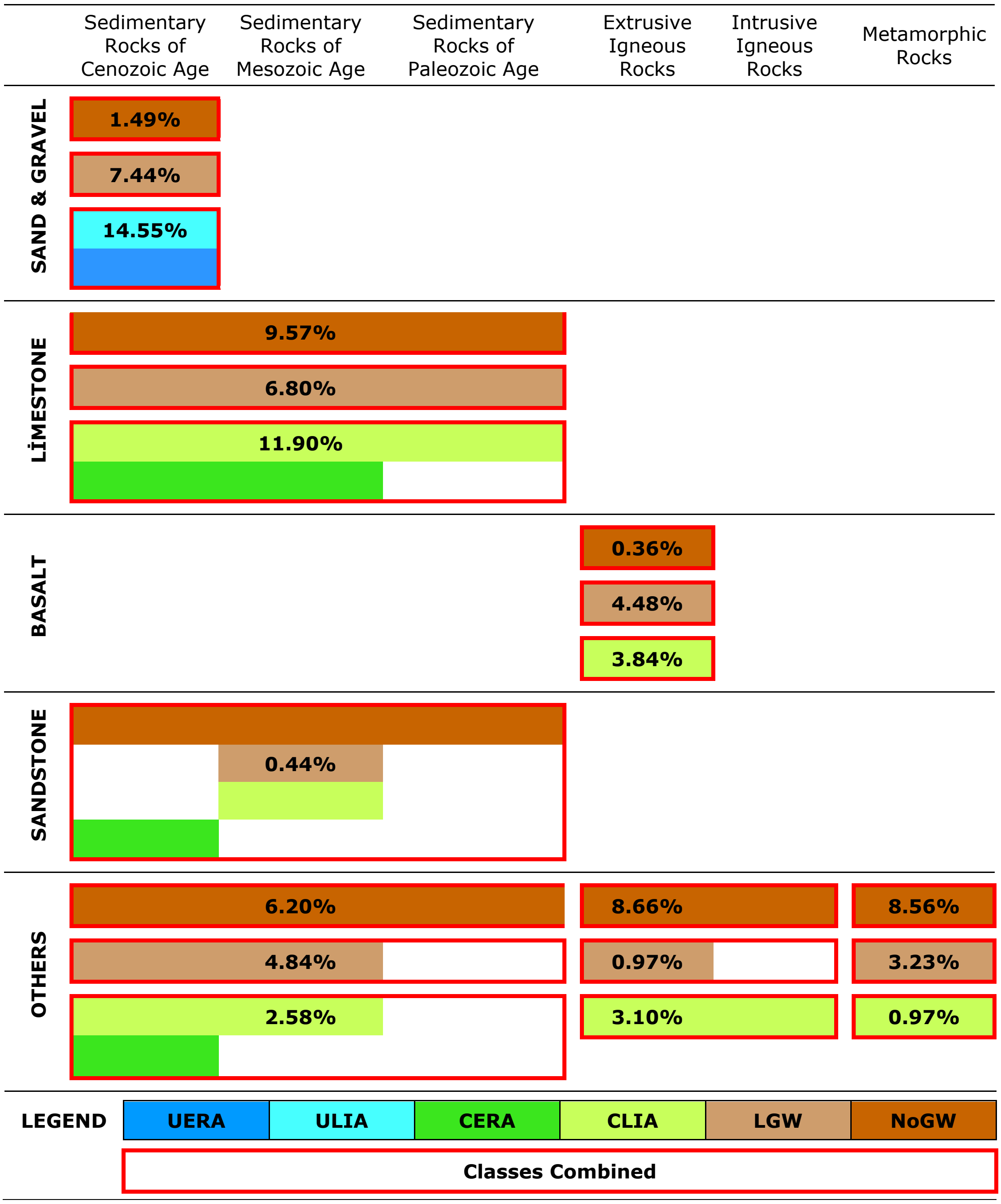
GW: Groundwater
UERA: Unconsolidated - Extensive and Rich Aquifers
ULIA: Unconsolidated - Local or Individual Aquifers
CERA: Consolidated - Extensive and Rich Aquifers
CLIA: Consolidated - Local or Individual Aquifers

Figure 5.24 Hydrogeological Map Assigned with Water-Bearing Rock Types

In order to delineate the groundwater bodies, a similar methodology was applied as it was done for delineation of the groundwater regions. The map given in Figure 5.24 was generalized by use of the procedure illustrated in Figure 5.18 to eliminate single or isolated formations. The same area threshold, 225km^2 was also used for this application. Differently, in this case, the formations were generalized with respect to those 40 classes defined in Table 5.12. However, the generalization in forty classes resulted in degradation of the integrity of some aquifer type formations. For example, contiguous sand and gravel formations that are colored with light blue and dark blue disappears with generalization, since the surface areas of these individual formations lies below the area threshold defined; whereas, these two formations having aquifer properties could be considered as a single groundwater body together. With this regard, the forty classes given in Table 5.12 were reclassified in nineteen classes as given in Table 5.13 to prevent these kinds of loses. On the other hand, the new classification disregards the age relations among formations which results in combination of contiguous groundwater bodies at different ages.

In order to get benefit from these two approaches, firstly, the map was generalized with respect to the classes given in Table 5.13, and then, with respect to forty classes defined in Table 5.12 (see Figure 5.25). The former generalized map was used as a guide for delineation of groundwater bodies, and the latter one was used to delineate the initial bodies according to geologic ages, where needed. Age classification was not applied in particular areas where it disturbs the integrity of the groundwater system. As it was done for delineation of the groundwater regions, the boundaries were adjusted to the actual formation boundaries. As a result of this analysis, a total of 279 groundwater bodies (excluding the islands) were identified in the study area. The map showing the delineated groundwater bodies can be seen in Figure 5.26.

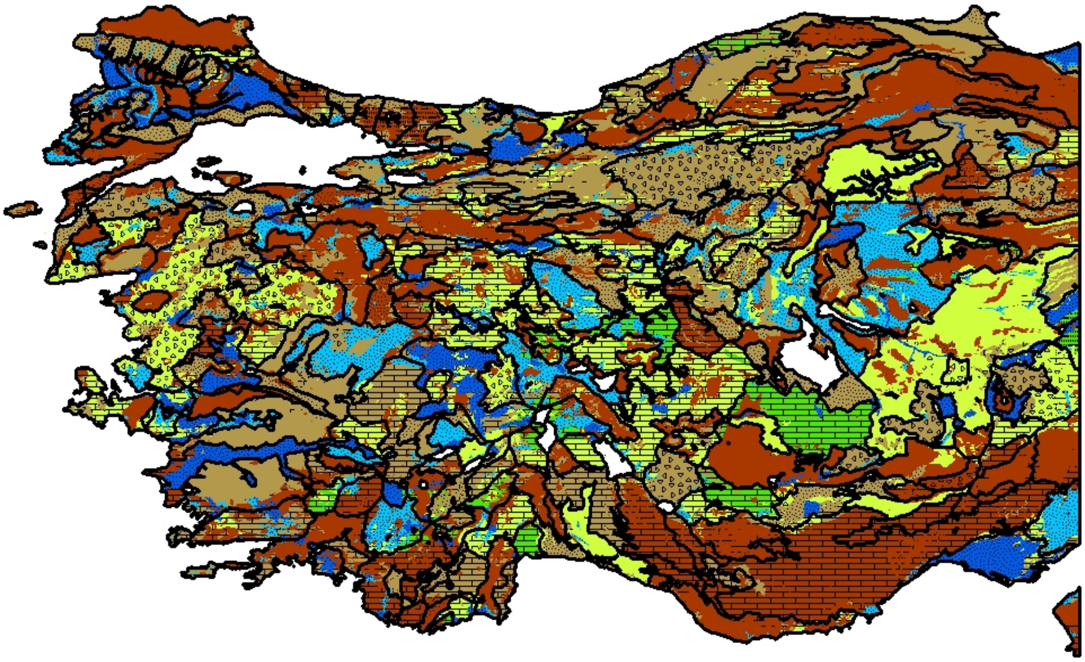
Table 5.13 Reclassification of Formations with respect to Geologic Age, Rock Type, and Aquifer Classification for Generalization (Areal Distribution in %)



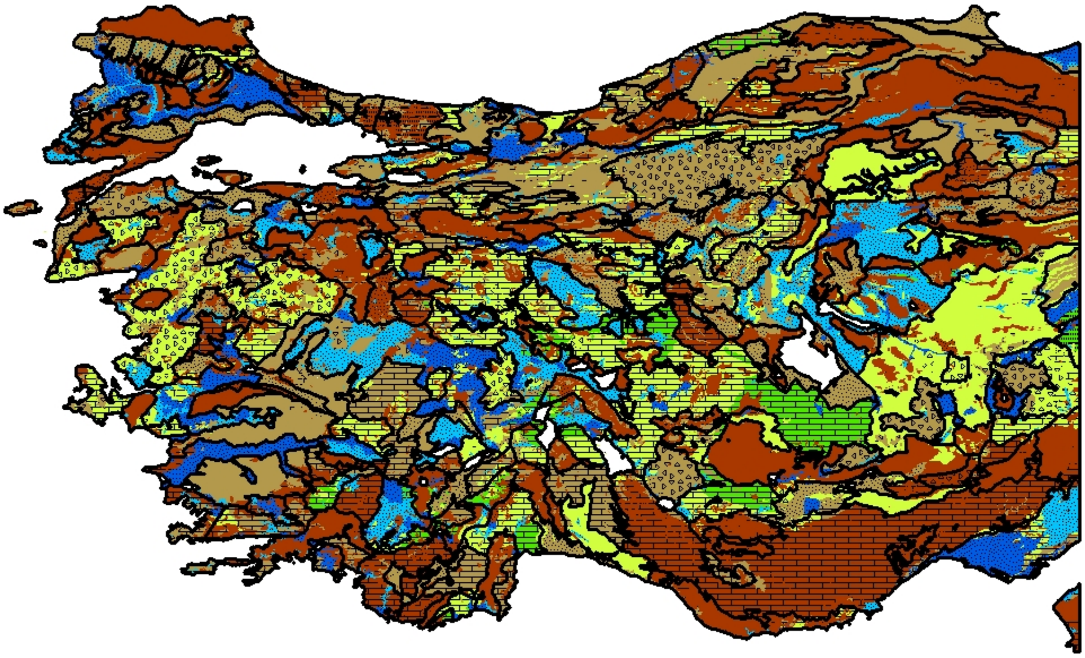
		Sedimentary Rocks of Cenozoic Age	Sedimentary Rocks of Mesozoic Age	Sedimentary Rocks of Paleozoic Age	Extrusive Igneous Rocks	Intrusive Igneous Rocks	Metamorphic Rocks
SAND & GRAVEL	NoGW	**1.49%**					
	LGW	**7.44%**					
	ULIA UERA	**14.55%**					
LİMESTONE	NoGW	**9.57%**					
	LGW	**6.80%**					
	CLIA CERA	**11.90%**					
BASALT	NoGW				**0.36%**		
	LGW				**4.48%**		
	CLIA				**3.84%**		
SANDSTONE	NoGW						
	LGW		**0.44%**				
	CLIA						
	CERA						
OTHERS	NoGW	**6.20%**			**8.66%**		**8.56%**
	LGW	**4.84%**			**0.97%**		**3.23%**
	CLIA CERA	**2.58%**			**3.10%**		**0.97%**

LEGEND **UERA** **ULIA** **CERA** **CLIA** **LGW** **NoGW**

Classes Combined

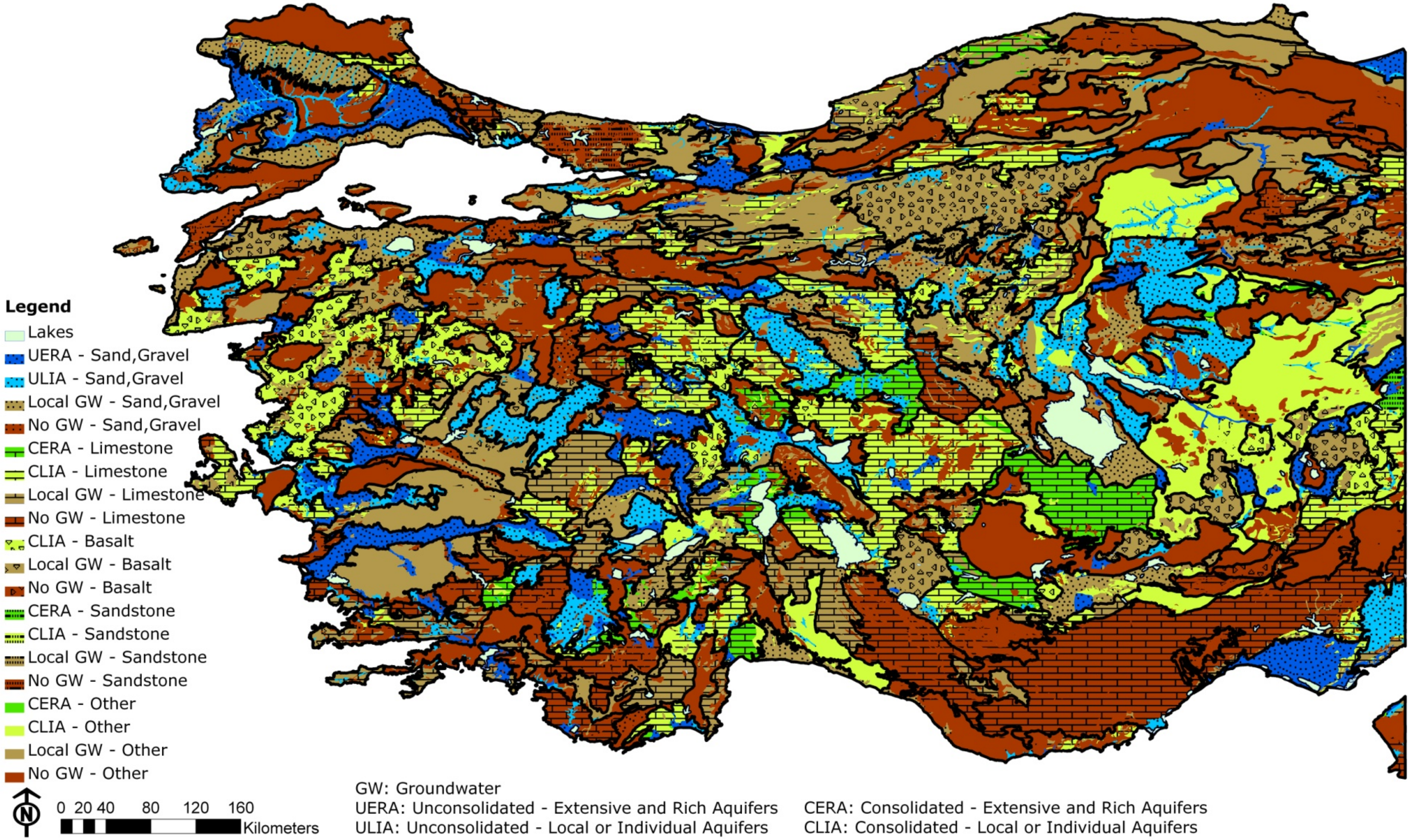


a) Generalization with respect to forty classes



b) Generalization with respect to nineteen classes

Figure 5.25 Generalized Maps by use of Two Classification Systems



GW: Groundwater
UERA: Unconsolidated - Extensive and Rich Aquifers
ULIA: Unconsolidated - Local or Individual Aquifers
CERA: Consolidated - Extensive and Rich Aquifers
CLIA: Consolidated - Local or Individual Aquifers

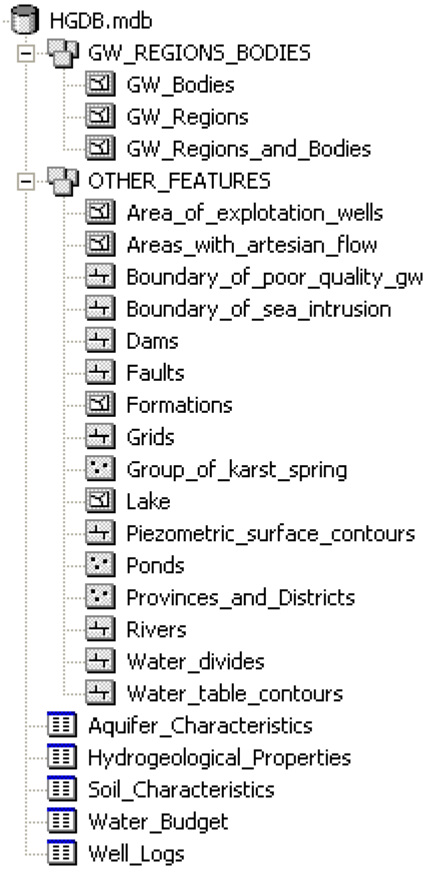
Figure 5.26 Map of Delineated Groundwater Bodies

5.2.5 Development of a Descriptive Database Infrastructure Specific to Groundwater Bodies

In addition to the delineation studies, as a part of hydrogeological database (HGDB), a descriptive database infrastructure specific to Groundwater Bodies (DISGB) was developed in order to keep records of hydrogeological parameters of each groundwater body under a defined structure in a systematic manner. As described in the following paragraphs, the DISGB includes general hydrogeologic, soil and aquifer characteristics, in addition to well data. The DISGB is expected to serve for multi-purpose uses. It is developed basically to orient the activities carried out in case of soil contamination. With this aim, the DISGB may serve for initial site characterization and development of conceptual site model, and consequently, development of sampling strategy.

For development of DISGB, the approaches of Hopkins (1989) and Newell et al. (1990) for development of a HGDB for groundwater modeling, the parameters forming DRASTIC (Aller et al., 1987), the parameters needed for estimation of DF (US EPA, 2002a), and the hydrogeological investigation reports prepared by DSİ were all taken into consideration. The parameters examined during site characterization, conceptual site model development and derivation of site-specific soil quality standards were considered.

Using the above descried approach, a DISGB with all elements given in Figure 5.27 was developed. The DISGB is a GIS geodatabase collecting a number of feature classes (including spatial data) and attribute tables (including temporal data). The database includes two feature datasets; groundwater regions and bodies, and other features. The former dataset stores information on the groundwater regions and bodies delineated and an attribute table presenting the characteristics of the formations. The latter one stores the features given in the hydrogeological map. In addition to these datasets, five attribute tables are formed. The contents of each attribute table are described below.



- HGDB.mdb
  - GW_REGIONS_BODIES
    - GW_Bodies
    - GW_Regions
    - GW_Regions_and_Bodies
  - OTHER_FEATURES
    - Area_of_explotation_wells
    - Areas_with_artesian_flow
    - Boundary_of_poor_quality_gw
    - Boundary_of_sea_intrusion
    - Dams
    - Faults
    - Formations
    - Grids
    - Group_of_karst_spring
    - Lake
    - Piezometric_surface_contours
    - Ponds
    - Provinces_and_Districts
    - Rivers
    - Water_divides
    - Water_table_contours
  - Aquifer_Characteristics
  - Hydrogeological_Properties
  - Soil_Characteristics
  - Water_Budget
  - Well_Logs

Figure 5.27 Elements of the HGDB Developed

i) Characteristics of the overlying strata surface: This table basically gives information about the characteristics of the formations observed at the surface strata with respect to hydrogeological map. The properties used for delineation of groundwater regions and groundwater bodies, such as aquifer classification, major rock groups, and rock types can be seen in this table. The name of groundwater region and the groundwater body covering each formation is designated in the table. The contents of the attribute table can be seen in Table 5.14.

ii) Hydrogeological properties of the formations: In this table, stratigraphical classification of formations by use of geochronologic units (era, period, sub-period, epoch) are given. Additionally, thickness of formation, lithology, physical features, and other features of formations are presented based on generalized stratigraphy. The source of information is recorded as the name and number of the hydrogeological investigation report used. The investigation site taking place under which groundwater body is also mentioned in the table. The contents of the table can be seen in Table 5.15.

Table 5.14 Structure of Database Table for Characteristics of the Overlying Strata

FIELD NAME	DESCRIPTION
OBJECTID	Object No
Shape_Length	Length of the Polygon (m)
Shape_Area	Surface Area of the Polygon (m^2)
GW_Region	Name of the Groundwater Region
GW_Body	Groundwater Body No
Color_Code	Color Code According to Aquifer Classification System
Aquifer_Type	Aquifer Classification of Hydrogeological Map
Notation	Mapping Notation used to Describe Formation
Main_Rock_Group	Main Rock Group
Age_or_Group	Age of Sedimentary Rocks or Sub-Group for Other Rocks
Period	Geochronology – Period
Rock_Type	Rock Type (Lithology)
Secondary_Rock_Type	Secondary Rock Type

Table 5.15 Structure of Database Table for Hydrogeological Properties of the Formations

FIELD NAME	DESCRIPTION
GW_BODY	Groundwater Body No
REPORT_NO	Investigation Report No
REPORT_SOURCE	Institution Preparing the Report, Year of Publication
ERA	Geochronology - Era
PERIOD	Geochronology – Period
LOWER_PERIOD	Geochronology – Lower Period
EPOCH	Geochronology – Epoch
THICKNESS	Thickness of Formation (m)
LITHOLOGY	Lithology
PHYSICAL_FEATURE	Physical Features
OTHER_FEATURES	Hydrogeological, Chemical and Other Features T: Transmissibility (m^3/day/m) EC: Specific Conductance (micromhos/cm)

iii) Soil characteristics: The main soil characteristics used for derivation of site-specific SQSs (standards for inhalation of volatiles and ingestion of groundwater pathways) and site characterization take place in this table. The contents of this table are given in Table 5.16.

Table 5.16 Structure of Database Table for Soil Characteristics

FIELD NAME	DESCRIPTION
GW_BODY	Groundwater Body No
SOIL_TYPE	Soil Texture
PARTCL_DENSTY	Soil Particle Density, ρ_s (kg/L)
DB_DENSITY	Dry Soil Bulk Density, ρ_d (kg/L)
MOISTURE_C	Gravimetric Soil Moisture Content, w (%)
MOIST_RTN_EXP	Moisture Retention Exponent, b
SATD_HYD_COND	Saturated Hydraulic Conductivity, K_s (m/yr)
POROSITY	Total Soil Porosity, n (L/L)
PORE_AIR	Air Filled Soil Porosity, θ_a (L/L)
PORE_WATER	Water Filled Soil Porosity, θ_w (L/L)
SOIL_FOC	Average Fraction of Organic Carbon of Soil, f_{oc} (g/g)
SOIL_PH	Average pH of Soil
INFILTRATION	Infiltration Rate, I (m/yr)

iv) Aquifer characteristics: The aquifer characteristics, such as transmissivity, hydraulic conductivity, seepage velocity, hydraulic gradient, etc. are given in this table based on the data from drilled boreholes and wells. The wells or boreholes placed in which groundwater body is also given in the table. The contents of this table can be seen in Table 5.17.

v) Well logs: The well logs are presented in this table. The table is connected to the previous one with the name and number of the well. The lithology is given with respect to depth in the well. Well screening and coverage are also shown in the table. The contents of this table can be seen in Table 5.18.

vi) Water budget: The parameters used to calculate water budget are presented in this table. With respect to the observation period, monthly averages and annual average data are presented in the table. The contents of the table can be seen in Table 5.19.

Table 5.17 Structure of Database Table for Aquifer Characteristics

FIELD NAME	DESCRIPTION
GW_BODY	Groundwater Body No
REPORT_NO	Investigation Report No
REPORT_SOURCE	Institution Preparing the Report, Year of Publication
WELL_NO	Well Number
WELL_NAME	Name of Well
DRILLING_PURPOSE	Purpose of Drilling
CONSTRUCTION_YR	Construction Year
GROUND_ALTITUDE	Topographic Altitude (m)
DEPTH	Depth of Well (m)
MEASUREMENT_DATE	Date of Measurement
STATIC_LEVEL	Static Level (depth from the surface to top of the aquifer) (m)
Q_ARTESIAN	Discharge of Artesian Well (L/sec)
Q_PUMP	Discharge of Pump Well (L/sec)
DRAWDOWN	Drawdown in the Well (m)
SPEC_CAPACITY	Specific Capacity of the Well (L/sec/m)
TRANSMISSIBILITY	Transmissibility, T (m^3/day/m)
SPECFC_CONDUCT	Specific Conductance (micromhos/cm)
WATER_CATEGORY	Category of Water
SATD_THICKNESS	Average Saturated Thickness of the Aquifer, d_a (m)
MEAN_GRAIN_SIZE	Mean Grain Size of the Aquifer Media, d_{50} (mm)
MAX_HYD_CONDUCT	Maximum Hydraulic Conductivity of the Aquifer, K_{max} (cm/sec)
AVE_HYD_CONDUCT	Average Hydraulic Conductivity of the Aquifer, K_{ave} (cm/sec)
MIN_HYD_CONDUCT	Minimum Hydraulic Conductivity of the Aquifer, K_{min} (cm/sec)
AVE_SEEPAGE_VEL	Average Groundwater Seepage Velocity, V (m/yr)
HYD_GRADIENT	Hydraulic Gradient, i (m/m)
ORGANIC_CARBON	Average Fraction of Organic Carbon, f_{oc} (g/g)
AVE_PH	Average pH of the Groundwater

Table 5.18 Structure of Database Table for Well Logs

FIELD NAME	DESCRIPTION
WELL_NO	Well Number
WELL_NAME	Name of Well
LITHOLOGY	Lithology
DEPTH_INITL	Initial Depth (m)
DEPTH_FNL	Final Depth (m)
FILTER	Well Screening (Yes / No)
CEMENT_OR_CLAY	Wellhead Sealed with Cement or Clay

Table 5.19 Structure of Database Table for Water Budget

FIELD NAME	**DESCRIPTION**
GW_BODY	Groundwater Body No
REPORT_NO	Investigation Report No
REPORT_SOURCE	Institution Preparing the Report, Year of Publication
STATION_NO	Code of Meteorological Station
STATION_NAME	Name of Meteorological Station
BTW_YEARS	Observation Years
TEMP_i	Average Temperature for month i (^oC)
TEMP_ANN	Annual Average Temperature (^oC)
EP_i	Average Evapotranspiration Potential for month i (mm)
EP_ANN	Annual Average Evapotranspiration Potential (mm)
PRECP_i	Average Precipitation for month i (mm)
PRECP_ANN	Annual Average Precipitation (mm)
PRECP_EP_i	Average Precipitation-EP for month i (mm)
PRECP_EP_ANN	Annual Average Precipitation-EP (mm)
RESERVE_WTR_i	Average Reserve Water for month i (mm)
RESERVE_WTR_ANN	Annual Average Reserve Water (mm)
ACTUAL_EP_i	Average Actual Evapotranspiration for month i (mm)
ACTUAL_EP_ANN	Annual Average Actual Evapotranspiration (mm)
DEFICIENT_WTR_i	Average Deficient Water for month i (mm)
DEFICIENT_WTR_ANN	Annual Average Deficient Water (mm)
EXCESS_WTR_i	Average Excess Water for month i (mm)
EXCESS_WTR_ANN	Annual Average Excess Water (mm)
FLOW_i	Average Flow for month i (mm)
FLOW_ANN	Annual Average Flow (mm)
DEF_FLW_PRECP_i	Average Deficiency of Flow According to the Precipitation for month i (mm)
DEF_FLW_PRECP_ANN	Annual Average Deficiency of Flow According to the Precipitation (mm)

* i denotes months from 1 to 12.

The attribute tables are connected to each other by one-to-one and one-to-many relationships. These relations are exhibited in Figure 5.28 and the fields connecting the attribute tables to each other are shown in Figure 5.29.

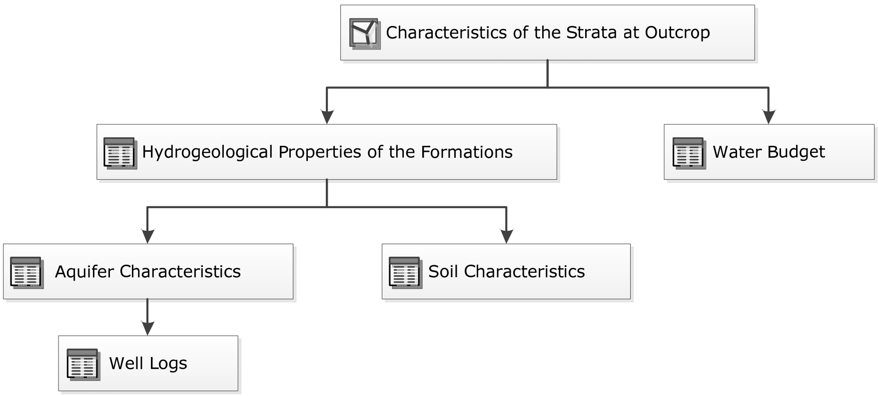
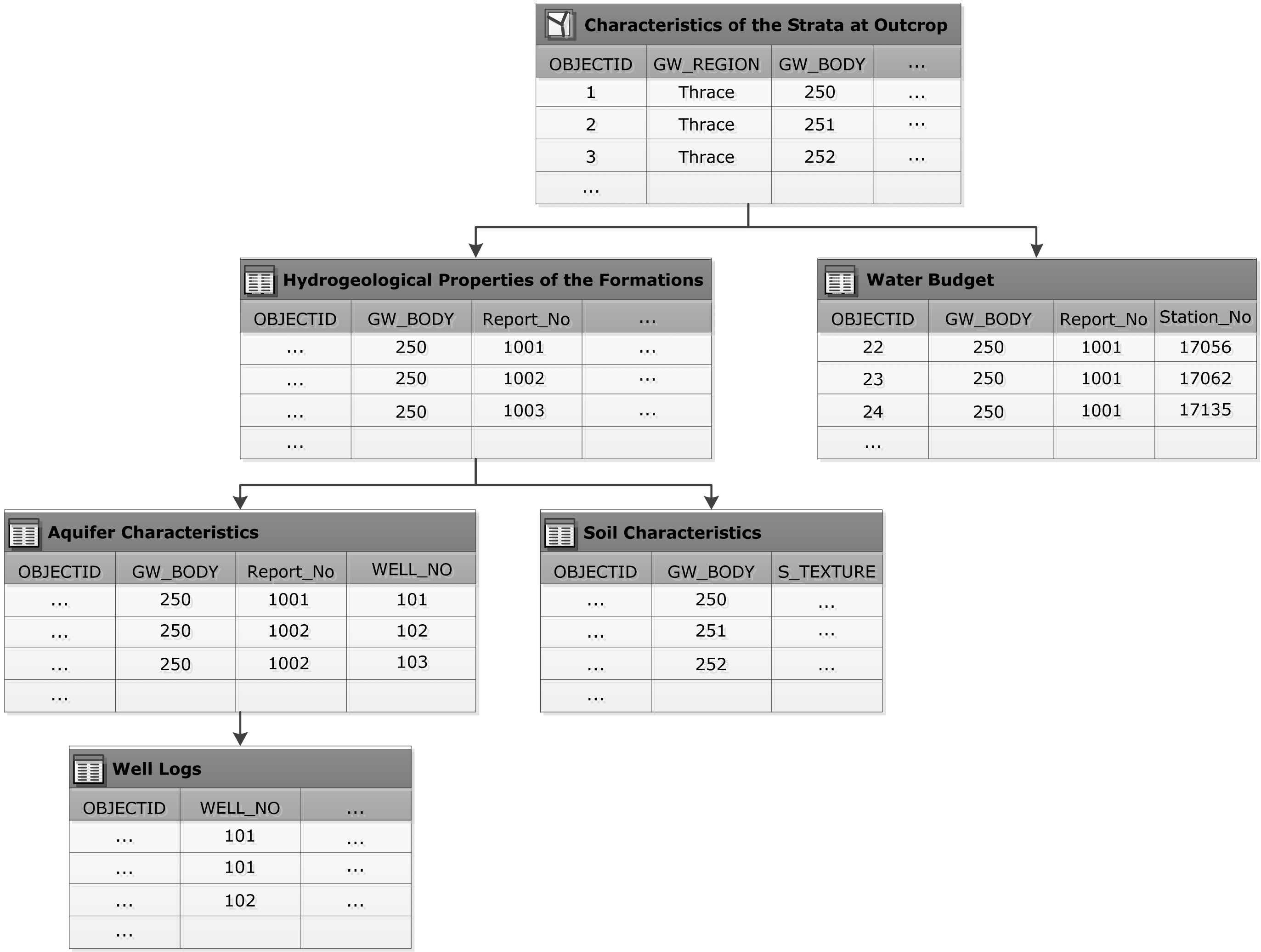


Figure 5.28 The Relationships between the Attribute Tables



Characteristics of the Strata at Outcrop

OBJECTID	GW_REGION	GW_BODY	…
1	Thrace	250	…
2	Thrace	251	…
3	Thrace	252	…
…			

Hydrogeological Properties of the Formations

OBJECTID	GW_BODY	Report_No	…
…	250	1001	…
…	250	1002	…
…	250	1003	…
…			

Water Budget

OBJECTID	GW_BODY	Report_No	Station_No
22	250	1001	17056
23	250	1001	17062
24	250	1001	17135
…			

Aquifer Characteristics

OBJECTID	GW_BODY	Report_No	WELL_NO
…	250	1001	101
…	250	1002	102
…	250	1002	103
…			

Soil Characteristics

OBJECTID	GW_BODY	S_TEXTURE
…	250	…
…	251	…
…	252	…
…		

Well Logs

OBJECTID	WELL_NO	…
…	101	…
…	101	…
…	102	…
…		

Figure 5.29 The Fields Connecting the Attribute Tables

5.3 RESULTS AND DISCUSSION

5.3.1 Results of the Study

A methodology described in Section 5.2 was used to develop a HGDB for Turkey which delineates groundwater regions and groundwater bodies, and contains a descriptive database infrastructure specific to groundwater regions and groundwater bodies. For development of this methodology, only the surface characteristics (overlying strata), which pertain priority importance especially for initial site assessment of soil and/or groundwater contamination, were taken into consideration. In this study, the descriptive database infrastructure specific to groundwater bodies (DISGB) could be utilized for assessment of soil and/or groundwater contamination, and for compilation of specific hydrogeological characteristics of each groundwater body.

As a result, the study area was divided into 13 groundwater regions, which designate similar stratigraphical, lithological and structural characteristics with respect to hydrogeologic mapping units. The surface areas of the groundwater regions range from 4,838km^2 to 112,312km^2. The areal distribution of the groundwater regions are given in Figure 5.30. Mediterranean Groundwater Region constitutes the largest groundwater region in the study area, whereas Upper Sakarya and Çukurova Groundwater Regions are the smallest regions.

Statistics for Area	
Count	13
Minimum	4,838
1st Quartile	15,552
Median	32,060
3rd Quartile	36,855
Maximum	112,312
Mean	33,477
Std. Deviation	30,280
Skewness	1.69
Kurtosis	3.18

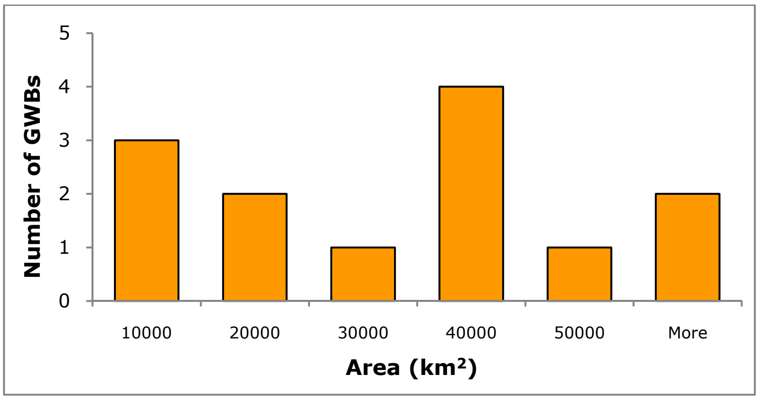


Figure 5.30 Statistics and Histogram for the Groundwater Regions

The groundwater bodies within each groundwater region, which pertain similar stratigraphy, lithology, structural properties and aquifer characteristics, were also delineated. The study area was divided into 279 groundwater bodies (excluding the islands). The areal distribution of the groundwater bodies and relevant statistics are presented in Figure 5.31. As can be seen from this figure, most of the groundwater bodies are smaller than $3,500km^2$. The largest groundwater body takes place in the Mediterranean Groundwater Region and mainly composed of non-water-bearing limestone of Cenozoic age.

Statistics for Area	
Count	279
Minimum	109
1st Quartile	504
Median	921
3rd Quartile	1,780
Maximum	20,299
Mean	1,561
Std. Deviation	2,100
Skewness	4.75
Kurtosis	31.83

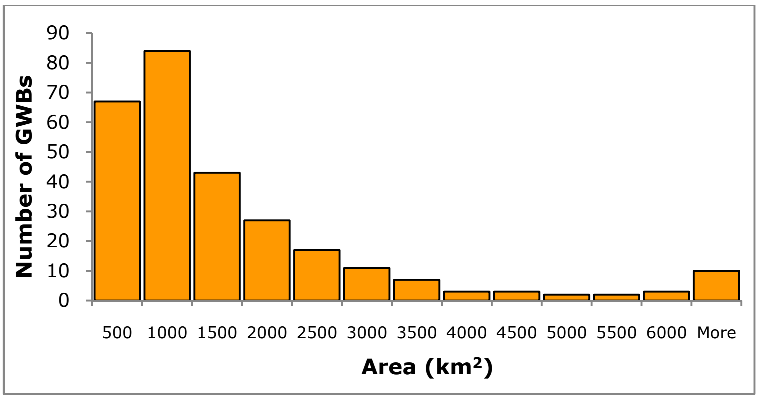


Figure 5.31 Statistics and Histogram for the Groundwater Bodies

Each groundwater body was also subjected to aquifer classification based on the dominant aquifer characteristics observed within the boundaries of the body. As a result of that study Table 5.20 was obtained.

Table 5.20 Classification of the Groundwater Bodies

	Aquifer Type	Number of Groundwater Bodies
🟦	Unconsolidated - Extensive and rich aquifers	21
🟦	Unconsolidated - Local or individual aquifers	17
🟩	Consolidated - Extensive and rich aquifers	10
🟩	Consolidated - Local or individual aquifers	50
🟫	Formations containing local groundwater	78
🟥	Formations do not containing groundwater	103
	TOTAL	279

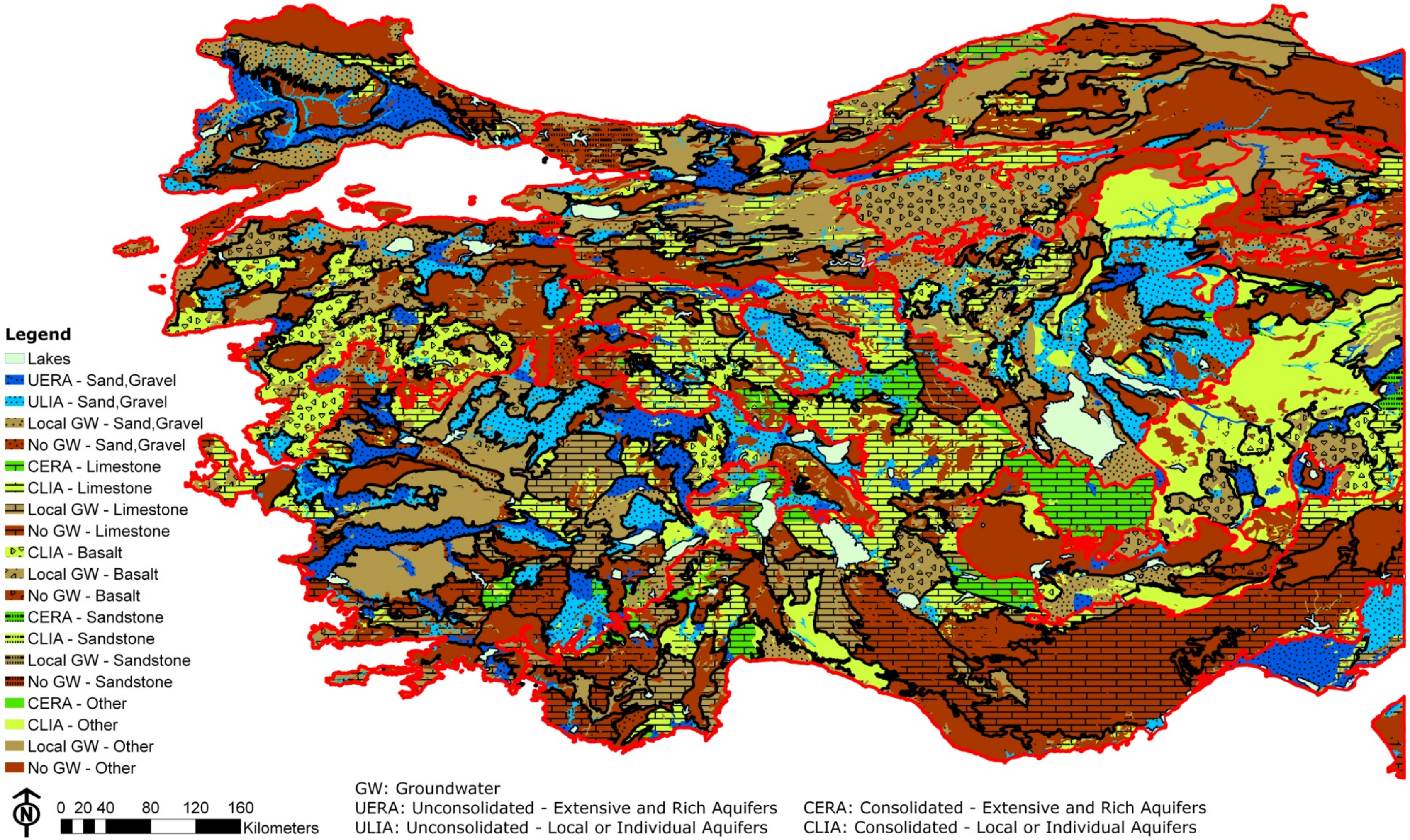
In order to see the relationship amongst the groundwater regions and bodies (shown in Figure 5.32) with the surface streams, river basin map of Turkey (Figure 5.33) was examined. A total of 26 river basins have been defined within Turkey and 19 of these basins (some of them partly) take place within the study area (Figure 5.34). The river basins are determined with the consideration of the catchment areas of main river systems and the natural drainage divides. As can be seen from Figure 5.34, although there are some overlaps, the boundaries of the groundwater regions do not completely compatible with river basin boundaries; at most places, drainage divides split groundwater bodies.

On the other hand, since groundwater regions and bodies were delineated based on the overlying strata, the geomorphological features designate compatibility with the formations and their water-bearing characteristics. As groundwater bodies are examined together with the geomorphological map of Turkey (Figure 5.35), the similarity can be observed clearly especially in some regions.

5.3.1 Discussions for the Study

The study area was divided into thirteen groundwater regions based on the similarity of rock units in terms of stratigraphy, lithology and structural properties. Each groundwater region was also divided into groundwater bodies with respect to the stratigraphy, lithology and structural properties in accompany of groundwater productivity of the body. In this way, each groundwater body representing the smallest groundwater units was also classified according to their aquifer or non-aquifer properties.

The percent distribution of the groundwater regions are shown in Figure 5.36 with respect to the area they occupy within the study area. In this plot, the aquifers types observed within each groundwater region are also presented. According to this figure; Çukurova, Yozgat-Nevşehir, Upper Sakarya, Central Anatolia, South Aegean and Mediterranean Groundwater Regions can be considered as the regions that contain significant groundwater resources. Especially, Çukurova and Upper Sakarya Groundwater Regions, most of which are composed of unconsolidated aquifers made of sand and gravel formations, are susceptible to groundwater contamination. Yozgat-Nevşehir and Mediterranean Groundwater Regions cover important limestone aquifers.



GW: Groundwater
UERA: Unconsolidated - Extensive and Rich Aquifers
ULIA: Unconsolidated - Local or Individual Aquifers
CERA: Consolidated - Extensive and Rich Aquifers
CLIA: Consolidated - Local or Individual Aquifers

Figure 5.32 Map of Delineated Groundwater Regions and Groundwater Bodies

Figure 5.33 River Basins within the Study Area

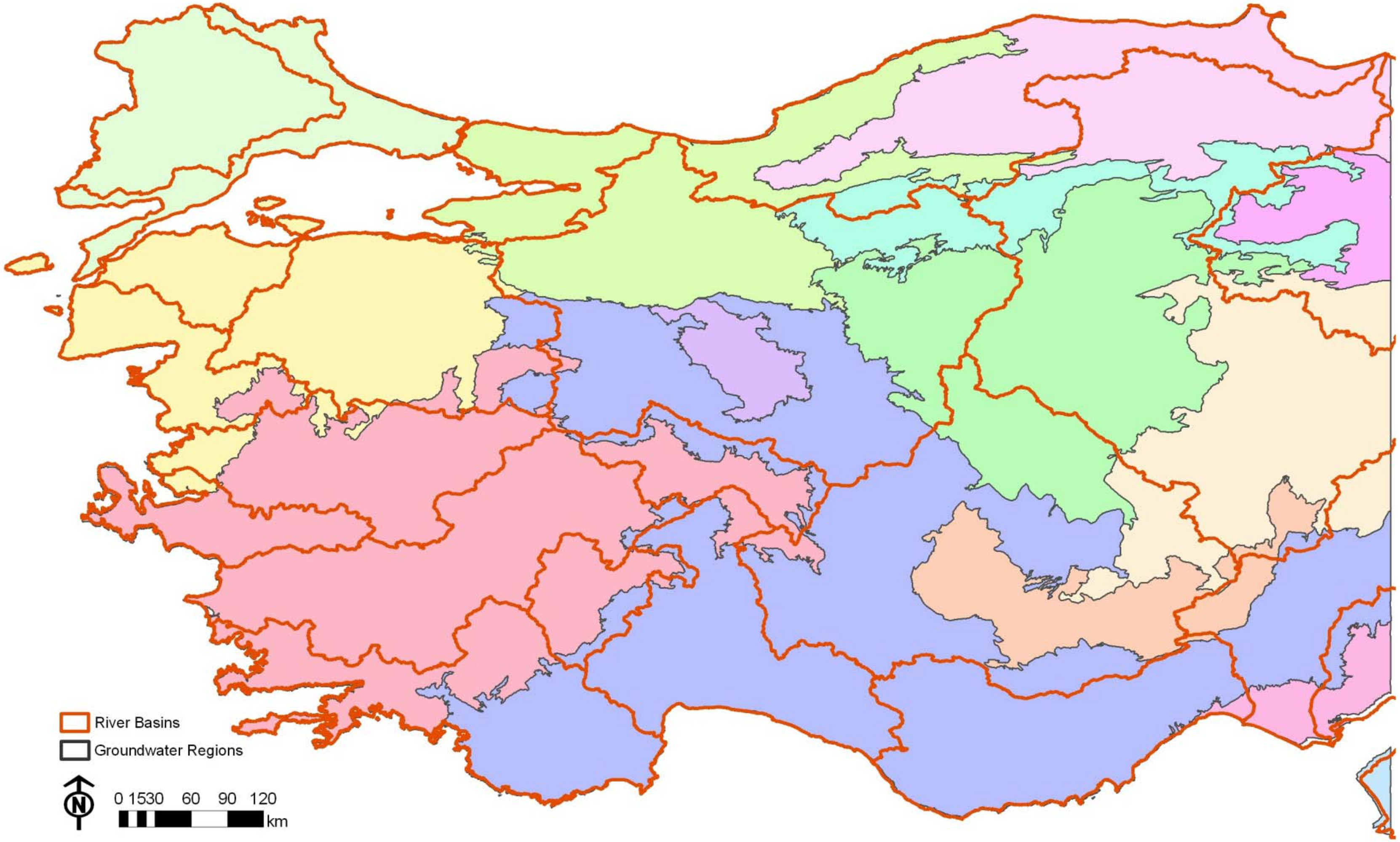


Figure 5.34 Relation of River Basins with Groundwater Regions

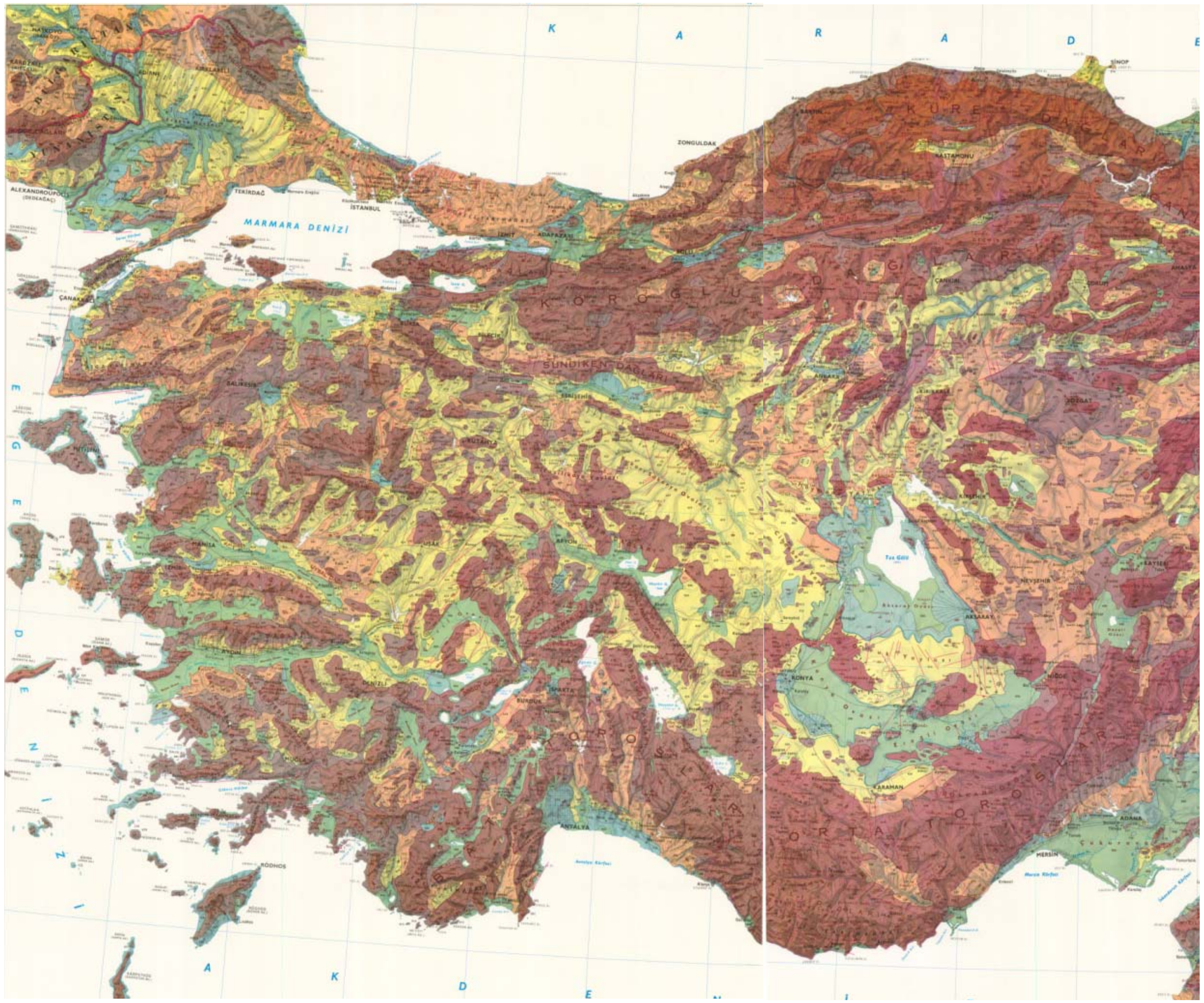


Figure 5.35 Geomorphology of the Study Area

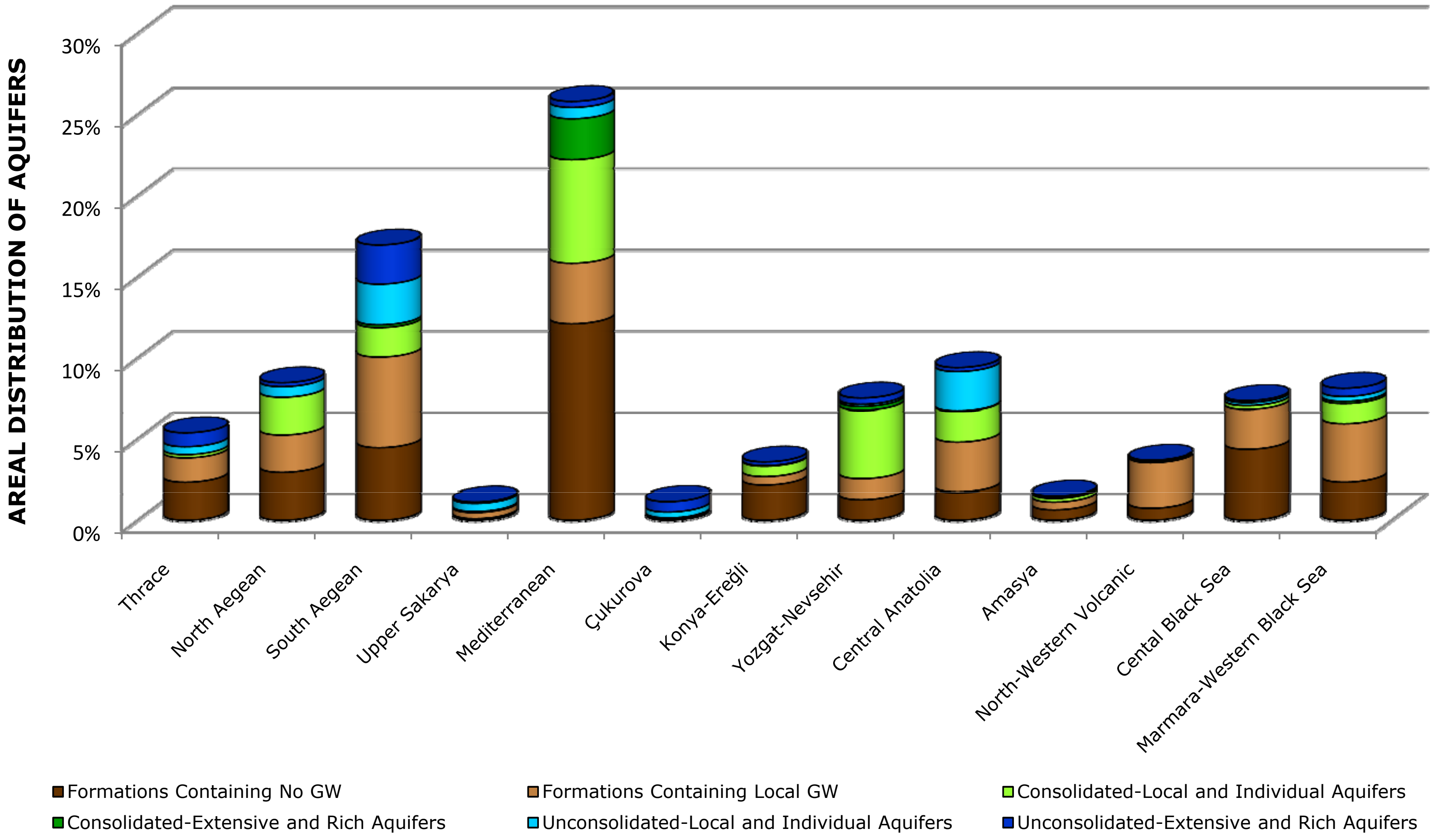


Figure 5.36 Areal Distribution (%) of the Aquifers within Each Groundwater Region

Particularly, in Mediterranean Groundwater Region, consolidated - extensive and rich aquifers are abundant, which should be protected against contamination. On the other hand, North Aegean, Thrace, and Marmara-Western Black Sea Groundwater Regions can be listed amongst moderate groundwater supplies. Especially, in North Aegean Groundwater Region, important aquifers made of andesite and basalt are found. Whereas, Konya-Ereğli, Amasya, Central Black Sea, and North-Western Volcanic Groundwater Regions mostly contain insignificant aquifers.

Despite some partial compliance, the boundaries of the groundwater regions and bodies do not coincide with the river basin boundaries, since basins are controlled by stream systems and drainage divides (Heath, 1984) and at most places drainage divides split groundwater regions and bodies. Each groundwater body designates a groundwater system and has peculiar characteristics. In order to point out the characteristics of each groundwater body, the framework of a DISGB was developed. The DISGB allows systematic recording of the hydrogeologic data for each groundwater body. Thus, the DISGB is considered as a useful tool for contaminated site management. For delineation of the groundwater regions and groundwater bodies, surface hydrogeological characteristics, which are important especially during initial site assessment, were utilized. Therefore, groundwater regions and bodies can be defined as 2-dimensional hydrogeologic units. However, with the integration of DISGB, the third dimension has been constructed. Nevertheless, necessary efforts should be put in for further development of 3-dimensional hydrogeologic units considering vertical cross-sections at site-specific basis as the data becomes available.

In the future, the study area is hoped to be enlarged up to the entire country and the database is continuously upgraded with the entry of new data obtained from contaminated site investigations. With accumulation of new site-specific data, the typical characteristics of groundwater bodies and/or regions would be displayed, which would facilitate and accelerate the primary actions and decisions to be taken regarding contaminated sites. The HGDB would serve for development of conceptual site model, site characterization and development of sampling strategy. In addition, the information gathered in the database could be used for derivation of generic and site-specific dilution factors and site-specific soil quality standards (for inhalation of volatiles ingestion of groundwater pathways). As vadose zone and aquifer characteristics are known, the threat on groundwater sources due to soil contamination might be estimated and necessary precautions might be taken in time. Besides, the database would also serve for groundwater modeling studies.

Although the HGDB was developed basically to deal with contaminated site management, it is expected to serve for multi-purpose uses. With compilation of new data, ranges of values for major hydrogeological parameters would be defined for each groundwater body and region, so that regional statistics would be produced for various parameters. Furthermore, the HGDB would constitute the infrastructure for groundwater vulnerability assessment studies. Consequently, the database may serve for identification of the locations of landfills or industrial sites/facilities to be established.

This study is also important since it puts in the initial efforts for delineation of groundwater bodies as required by WFD. However, in this study, different from the definition of WFD, groundwater bodies are considered as the mappable smallest groundwater systems which can have either aquifer or non-aquifer characteristics.

As a conclusion, groundwater regions and bodies are seen as sub-units of groundwater systems and such delineation is vital for management of groundwater systems. The HGDB constitutes the essential basic tool for development of generic and site-specific SQSs and reasonable *DFs.* The database may also be used for planning activities related to contaminated site management and groundwater resources management.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY AND CONCLUSIONS

In this study, a two-phased approach was used for development of human health risk based SQSs for Turkey. In the first phase of the study, the *conceptual framework* for derivation of human health risk based SQSs was established. Under this phase, the approaches of various countries were reviewed. With the insight gained, the needs of Turkish regulation in terms of SQSs were identified. The potentially soil polluting activities in Turkey and the potential soil pollutants associated with those activities were identified with consideration of the soil contamination events experienced in EU. The approach to be followed and the key elements for derivation of human health risk based SQSs were determined. The exposure scenarios of concern for Turkey and generic human exposure and contact rates valid for these scenarios were determined. The generic soil characteristics (i.e. soil texture, soil pH, f_{oc}, ρ_b, ρ_s, n, θ_w, and θ_a) were derived by use of information on general soil properties of Turkey. The physical-chemical and toxicological data needed to derive human health risk based SQSs were identified, the databases including these data were examined and the necessary data were compiled from reliable sources.

For development of human health risk based SQSs for Turkey, meteorological conditions of the country were also considered. Because meteorological conditions play important role in dispersion of volatile and particulate emissions arising from contaminated soil. In order to calculate generic SQSs for inhalation volatiles and fugitive dusts, the air dispersion factors representing the inverse of the air concentration of pollutants (mg/m^3) per emission flux (g/m^2.s) were needed to be specified with respect to the prevailing meteorological conditions in the country. For this purpose, an air dispersion model (AERMOD) was run by using 7 years of hourly meteorological data for 7 meteorological stations, for which atmospheric profiles of wind speed and direction, temperature, relative humidity are recorded twice-daily with respect to pressure and height from surface level. Generic air dispersion factors for volatile and fugitive dust emissions were determined using the model results. In addition to these studies, air dispersion factors were determined for each station as a function of source size, which would then be used for derivation of site-specific SQSs for different source sizes.

Modeling studies have shown that, other than the prevalent meteorological conditions, use of different air dispersion models (i.e., AERMOD and ISCST3) and different assumptions in modeling studies (e.g., receptor height and surface roughness height) result in significant differences in model outputs. For this reason, the relevant conservative assumptions (e.g., ground level receptor and surface roughness height for barren land in suburban residential area) were made for derivation of air dispersion factors for Turkey.

It has been shown that the calculated SQSs are highly sensitive to the built generic site characteristics, the assumptions made and chemical-specific data used in calculations. Therefore, scientifically sound generic site characteristics (soil, hydrogeological and meteorological characteristics) has to be specified for derivation of SQSs. Conservative assumptions has to be used while specifying the generic site characteristics. Since SQSs derivation process is very dynamic in nature and large amount of information and data used in calculations, scientific tools has to be developed compatible with the developed methodology.

In order to maintain the sustainability and currency of the developed SQSs, and to provide data and information needed in calculation of generic and site-specific SQSs, the *technical infrastructure* for derivation of risk based SQSs was established. One of the tools developed for this purpose was the *exposure model* (computational tool) called as TRSOIL. This exposure model integrates the SQSs derivation procedure with the information and data used in calculations. Thus, any changes in exposure rates, generic site characteristics, and chemical specific physical-chemical and toxicological data could be reflected to calculations easily. TRSOIL was developed as a MS Excel based exposure model with several user forms prepared by using Visual Basic Applications (VBA). TRSOIL can be operated either in English or Turkish. It has two main functions; (i) calculation of generic or site-specific SQSs, and (ii) physical-chemical and toxicological data management. By using TRSOIL, generic and site-specific SQSs can be calculated easily and potential calculation mistakes that may result due to the use of various parameter values and chemical-specific data in calculations can be eliminated. Besides, chemical-specific data, exposure parameters and site characteristics used in calculations can be updated/upgraded. Therefore, it is believed that the developed exposure model will help to keep up with the dynamic nature of the SQSs derivation process and aid the regulatory authorities and other stakeholders during assessment of contaminated sites or for updating risk based generic SQSs that may be deemed necessary in the future.

Another tool that has been developed to strengthen the *technical infrastructure* for derivation of risk based SQSs is the hydrogeological database (HGDB). A Geographical Information Systems (GIS) based HGDB, which includes the general soil and hydrogeologic characteristics of a site needed for human health risk assessment studies, was developed. This database can be coupled with TRSOIL in the future for determination of the generic and site-specific soil and hydrogeological characteristics which affect the derivation of SQSs for inhalation of volatiles and ingestion of contaminated groundwater pathways. The developed HGDB can provide information and data not only for determination of the site characteristics, but also for the derivation of scientifically based *DFs*, development of pertinent conceptual site models (CSMs) and development of accurate sampling strategies. The main data gap for derivation of SQSs for Turkey was encountered during derivation of *DF* which is important for migration to groundwater pathway. The specified *DF*, therefore, can be over-conservative which needs verification. National distribution of aquifer parameters needed for verification purpose can be compiled through the developed HGDB.

The structure of this HGDB was established based on the regional and local hydrogeologic units called groundwater regions and groundwater bodies, respectively. A methodology was built up for delineation of these hydrogeological units and a descriptive database structure was constructed based on the local hydrogeological units (i.e., groundwater bodies). By use of this methodology, the study area (Western and Central Anatolia) was delineated into thirteen groundwater regions based on the similarity of rock units in terms of stratigraphy, lithology and structural properties. Each groundwater region was also divided into groundwater bodies with respect to the stratigraphy, lithology and structural properties in accompany of groundwater productivity of the body. The descriptive database infrastructure specific to groundwater regions and groundwater bodies, which includes information and data on the general hydrogeological properties, aquifer characteristics (e.g., hydraulic conductivity, aquifer thickness, etc.), soil characteristics, water budget and well logs, was developed.

Although the HGDB was developed basically to deal with contaminated site management, it is expected to serve for other purposes. With compilation of new data, ranges of values for major hydrogeological parameters can be defined for each groundwater body and region, so that regional statistics can be produced for various parameters. In the future, the study area is hoped to be enlarged up to the entire country and the database is continuously upgraded with the entry of new data obtained from contaminated site investigations. With accumulation of new site-specific data, HGDB would become a useful source of information for estimation of the regional and local soil and hydrogeologic characteristics. Consequently the HGDB could be utilized for derivation of more reasonable generic *DF* for Turkey, which could not been achieved currently due to deficiency of data. Besides, the generic site characteristics specified in this study can be upgraded in conjunction with the availability of more detailed data or inventory for contaminated sites to be established in the future.

On the other hand, the methodology established for delineation of groundwater regions and groundwater bodies, and the structure of the HGDB may constitute the initial studies to fulfill the requirements of the EU WFD (EU COM, 2000) for determination of the groundwater bodies at risk and implementation of the essential measures to protect groundwater systems that are vulnerable to contamination.

To sum up, the conceptual framework and the technical infrastructure developed for derivation of Turkish SQSs will contribute to contaminated site management in Turkey and assist regulatory authorities and other stakeholders in Turkey during site assessment studies.

6.2 RECOMMENDATIONS FOR FUTURE STUDIES

The developed SQSs are subject to periodic upgrade and update. Thus, necessary efforts should be put in for upgrade of generic site characteristics with the recently obtained field data, development of scientifically based *DFs* for Turkey, monitoring recent chemical-specific data and re-calculation of generic SQSs accordingly.

In this thesis, the human health risk based SQSs were developed for residential and commercial/industrial land use scenarios by considering four generic exposure pathways (i.e., ingestion-dermal contact, inhalation of volatiles, inhalation of fugitive dusts and ingestion of contaminated groundwater). However, additional exposure scenarios (e.g. agricultural land use) and pathways (e.g., inhalation of volatiles in indoor air) may be considered for development of generic SQSs in the future depending on the requirements in this field. Besides, it is known that ecological risk based SQSs are vital for protection of the ecosystem. Thus, future studies should focus on this subject.

The developed exposure model, TRSOIL, may be improved further by integration of the calculation procedure for additional land use scenarios and pathways and/or by integration of the modules for Tier 2 level risk assessment.

In this study, the delineation of groundwater regions and groundwater bodies is performed based on the information available. However, the delineation methodology may be improved further by integration of other related data, such as vertical hydrogeological characteristics and recharge-discharge locations.

The developed HGDB can be improved further by including the information on the location of contaminated site and source characteristics to the database. The assessment reports to be submitted to the MoEF may be used for this purpose. Furthermore, this HGDB may be expanded by web-based applications. Hence, the data gathered in the HGDB can be used as a guide for future site assessments, statistical analysis or development of generic site characteristics.

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APPENDIX-A

INTERNATIONAL SOURCES PRODUCING TOXICITY ASSESSMENT RESULTS

The international sources/databases, namely IRIS, HEAST, ATSDR, EFSA, JECFA, JMPR, IPCS, California-OEHHA, Health Canada, RIVM, TERA, providing toxicity assessment results are presented in Table A.1.

Table A.1 International Sources Producing Toxicity Assessment Results

SOURCE	NAME OF CRITICAL EXPOSURE VALUE	DESCRIPTION
IRIS (Integrated Risk Information System) and **HEAST** (Health Effects Assessment Summary Tables)	*RfD* (Oral Reference Dose) *SF* (Oral Slope Factor)	The IRIS is an electronic database containing information on human health effects that may result from exposure to various substances in the environment. IRIS is prepared and maintained by the US EPA's National Center for Environmental Assessment (NCEA) within the Office of Research and Development. The Radionuclide Table (formerly HEAST Slope Factors) lists ingestion, inhalation and external exposure cancer slope factors for radionuclides. EPA classifies all radionuclides as known human cancer causing agents (URL 18 and URL 19).
ATSDR (Agency for Toxic Substances & Disease Registry)	*MRL* (Minimal Risk Level)	ATSDR, based in Atlanta, Georgia, is a federal public health agency of the US Department of Health and Human Services. ATSDR produces "toxicological profiles" for hazardous substances found at sites. These hazardous substances are ranked based on frequency of occurrence at NPL sites, toxicity, and potential for human exposure. Toxicological profiles are developed from a priority list of 275 substances. ATSDR also prepares toxicological profiles for the Department of Defense and the Department of Energy on substances related to federal sites. So far, 302 toxicological profiles have been published or are under development as "finals" or "drafts for public comment". These profiles cover more than 250 substances (URL 20).
EFSA (European Food Safety Authority)	*ADI* (Acceptable Daily Intake) *TDI* (Tolerable Daily Intake) *UL* (Tolerable Upper Intake Level)	EFSA is the keystone of EU risk assessment regarding food and feed safety. In close collaboration with national authorities and in open consultation with its stakeholders, EFSA provides independent scientific advice and clear communication on existing and emerging risks. Since mid-2003, EFSA has been responsible for Europe's product peer review of active substances used in plant protection products. This task is carried out by EFSA's Pesticide Risk Assessment Peer Review (PRAPeR) in line with legally agreed procedures. PRAPeR is also engaged in the risk assessment of Maximum Residue Levels (MRLs) in accordance with the provisions of Regulation (EC) No 396/2005. PRAPeR is involved in the process of assessing the safety of the proposed temporary European MRLs for a range of substances for which harmonized EU MRLs have not yet been agreed (URL 21).

Table A.1 International Sources Producing Toxicity Assessment Results (cont'd)

SOURCE	NAME OF CRITICAL EXPOSURE VALUE	DESCRIPTION
JECFA (The Joint FAO/WHO Expert Committee on Food Additives)	*ADI* (Acceptable Daily Intake) *TDI* (Tolerable Daily Intake)	JECFA is an international scientific expert committee that is administered jointly by the Food and Agriculture Organization of the United Nations (FAO) and the WHO. It has been working since 1956, initially to evaluate the safety of food additives. Its work now also includes the evaluation of contaminants, naturally occurring toxicants and residues of veterinary drugs in food. To date, JECFA has evaluated more than 1500 food additives, approximately 40 contaminants and naturally occurring toxicants, and residues of approximately 90 veterinary drugs. The Committee has also developed principles for the safety assessment of chemicals in food that are consistent with current thinking on risk assessment and take account of recent developments in toxicology and other relevant sciences (URL 22).
JMPR (The Joint FAO/WHO Meeting on Pesticide Residues)	*ADI* (Acceptable Daily Intake)	JMPR is an international expert scientific group that is administered jointly by the FAO and the WHO. The FAO Panel of Experts is responsible for reviewing residue and analytical aspects of the pesticides under consideration, including data on their metabolism, fate in the environment, and use patterns, and for estimating the maximum residue levels that might occur as a result of the use of the pesticides according to good agricultural practices. The WHO Core Assessment Group is responsible for reviewing toxicological and related data and for estimating, where possible, acceptable daily intakes (ADIs) for humans of the pesticides under consideration (URL 23).
IPCS (The International Programme on Chemical Safety)	Guidance value	IPCS, established in 1980, is a joint venture of the United Nations Environment Programme (UNEP), the International Labor Organization (ILO) and the WHO. The overall objectives of the IPCS are to establish the scientific basis for assessment of the risk to human health and the environment from exposure to chemicals, through international peer review processes, as a prerequisite for the promotion of chemical safety, and to provide technical assistance in strengthening national capacities for the sound management of chemicals (URL 24).

Table A.1 International Sources Producing Toxicity Assessment Results (cont'd)

SOURCE	NAME OF CRITICAL EXPOSURE VALUE	DESCRIPTION
California-OEHHA (Office of Environmental Health Hazard Assessment)	*RfD* (Reference Dose) *REL* (Reference Exposure Level)	The California Wildlife Biology, Exposure Factor, and Toxicity Database (Cal/Ecotox) is a compilation of ecological, physiological data, and toxicity data for a number of California mammals, birds, amphibians, reptiles and fish. Cal/Ecotox is searchable by species or chemical. The database has been created by the OEHHA, in collaboration with the University of California at Davis, to provide an information resource for risk assessors conducting ecological risk assessments in California (URL 25).
Health Canada	*TDI* (Tolerable Daily Intake)	Health Canada is the Federal department responsible for helping Canadians maintain and improve their health, while respecting individual choices and circumstances. The Priority Substances List and the assessments of risks to human health or the environment posed by various substances are published by Health Canada (URL 26).
RIVM (National Institute of Public Health and Environment, the Netherlands)	*TDI* (Tolerable Daily Intake) *TCA* (Tolerable Concentration in Air) *MPR* (Maximum Permissible Risk) or Critical Exposure Value	RIVM is a recognized leading centre of expertise in the fields of health, nutrition and environmental protection. The Institute works mainly for the Dutch government and share their knowledge with governments and supranational bodies around the world. The results of the research, monitoring, modeling and risk assessment are used to underpin policy on public health, food, safety and the environment. RIVM monitors the effects of radiation, estimating the risks of hazardous substances, assessing environmental quality, investigating environmental effects on public health and the monitoring of air, water and soil quality (URL 27).
TERA (Toxicology Excellence for Risk Assessment)	Database of values	TERA is a non-profit, corporation organized for scientific and educational purposes. TERA is developing and communicating risk assessment information, sponsoring peer reviews and consultations, improving risk methods through research, and educating the public on risk assessment issues. ITER is a free Internet database of human health risk values and cancer classifications for over 600 chemicals of environmental concern from multiple organizations worldwide. ITER is the only database that presents risk data in a tabular format for easy comparison, along with a synopsis explaining differences in data and a link to each organization for more information (URL 28).

APPENDIX-B

POTENTIAL SOIL POLLUTANTS ASSOCIATED WITH POTENTIALLY SOIL POLLUTING ACTIVITIES

The potentially soil polluting activities important for Turkey are listed in Table B.1 with respect to their NACE Codes and potential soil pollutants (or groups of pollutants) associated with these activities are also indicated.

The soil pollutants included in the regulations of other countries (i.e., US EPA, Germany, France, the Netherlands, Spain, Canada and Norway) are presented in Table B.2.

Table B.1 Soil Contaminants associated with the Industries

NACE CODE	INDUSTRY	ORGANIC COMPOUNDS	INORGANICS
11	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying	BTEX, MTBE, NMVOC, PAHs, PCBs, TPH, Phenols, Aliphatic hydrocarbons, Organolead compounds	As, Ba, Cd, Co, Cr, Cu, Ni, Pb, V, Zn
13	Mining of metal ores	BTEX, PAHs, PCBs, TPH	As, Ba, Cd, Co, Cr, Cu, Hg, Ni, Pb, V, Zn
14.12	Quarrying of limestone, gypsum and chalk	BTEX, PAHs, PCBs, TPH	-
14.22	Mining of clays and kaolin	BTEX, PAHs, PCBs, TPH	-
15	Manufacture of food products and beverages	Acetaldehyde, Acetone, Ethylene glycol, Methanol, Pesticides, HFCs	Cd, Hg
15.1	Production, processing and preserving of meat and meat products	BTEX, HFCs, PAHs, VHH, Pesticides, Phenols	As, Cd, Cr
15.4	Manufacture of vegetable and animal oils and fats	Phenols and Organic acids	Cu, Fe, Mn
15.7	Manufacture of prepared animal feeds	BTEX, PAHs, VHH, Pesticides, Phenols	As, Cd, Cr
15.98	Production of mineral waters and soft drinks	BTEX, PAHs, PCBs	Cu, Cr, Pb, Zn
16	Manufacture of tobacco products	Propylene, Toluene, Acetone, Styrene, 2-Ethoxyethanol, Dibutyl phthalate, Methanol	As, Ba, Br, Cd, Hg, Pb, Sb & Zn compounds
17.3	Finishing of textiles	BTEX, NMVOC, PAHs, TPH, PCPs, Pesticides, Phenols, Chlorophenols	Al, B, Cd, Cr, Cu, Hg, Sn, Ti, Zn
18.1	Manufacture of leather clothes	PAHs, Toluene, Methyl ethyl ketone, Acetone, Glycol ethers, Xylene, Methyl isobutyl ketone	Cd, Cr, Mn
18.2	Manufacture of other wearing apparel and accessories	1,1,1-Trichloroethane, Methyl ethyl ketone, Toluene, Dichloromethane, Acetone, Xylene, Tetrachloroethylene	As, B, Cr, Cu, Mn, Sb, Zn

Table B.1 Soil Contaminants associated with the Industries (Cont'd)

NACE CODE	INDUSTRY	ORGANIC COMPOUNDS	INORGANICS
19.1	Tanning and dressing of leather	BTEX, MTBE, VHH, Aliphatic hydrocarbons, phenols	Cr^{3+}, Cr^{6+}, Cd, Pb
19.3	Manufacture of footwear	PAHs, Toluene, Methyl ethyl ketone, Acetone, Glycol ethers, Xylene, Methyl isobutyl ketone	Cd, Cr, Mn
20.1	Sawmilling and planing of wood; impregnation of wood	BTEX, PAHs, PCBs, Phenols, Total chlorophenols, Phenols, Pesticides, Aliphatic hydrocarbons, Organotin compounds	As, Cu, Cr, Hg, Ni, Pb, Zn
21.1	Manufacture of pulp, paper and paperboard	PAHs, PCBs, NMVOC, TPH, VHH, Pesticides, Phenols, Chlorophenols, Dioxins, Furans, Aliphatic hydrocarbons	As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Zn
22.2	Printing and service activities related to printing	BTEX, PAHs, PCBs, VHH, Phenols, Organotin compounds	Ba, Cd, Cr, Cu, Ni, Pb, Se, Zn
23	Manufacture of coke, refined petroleum products and nuclear fuel	BTEX, MTBE, NWVOC, PAHs, PCBs, TPH, Phenols, Aliphatic hydrocarbons, Organolead compounds	As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, V, Zn, CN
24.1	Manufacture of basic chemicals	PAHs, TPH	As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Se, V, Zn
24.2	Manufacture of pesticides and other agro-chemical products	BTEX, PAHs, TPH, VHH, Chlorophenols, Dioxins, Furans, Aliphatic hydrocarbons, Organotin compounds	As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Zn
24.3	Manufacture of paints, varnishes and similar coatings, printing ink and mastic	BTEX, PAHs, PCBs, VHH, Phenols, Organotin compounds	Ba, Cd, Cr, Cu, Ni, Pb, Ti, Zn
24.4	Manufacture of pharmaceuticals, medicinal chemicals and botanical products	BTEX, DCM, NMVOC, PAHs, PER, TCM, TRI, VHH, Chlorophenols, Aliphatic hydrocarbons, Chlorinated aromatic hydrocarbons	As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, V, Zn

Table B.1 Soil Contaminants associated with the Industries (Cont'd)

NACE CODE	INDUSTRY	ORGANIC COMPOUNDS	INORGANICS
24.5	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	BTEX, PAHs, PAE, PCBs, VHH, Phenols, Chlorophenols, Dioxins, Furans, Chlorinated aromatic hydrocarbons	As, B, Ba, Cr, Cu, Hg, Ni, Pb, Zn
25.1	Manufacture of rubber products	BTEX, PAHs, TPH, VHH, Phenols, Chlorophenols, Aliphatic hydrocarbons, Chlorinated aromatic hydrocarbons	As, Cd, Cr, Cu, Ni, Pb, S, Zn
25.2	Manufacture of plastic products	BTEX, PCBs, Acetone, Dichloromethane, Methyl ethyl ketone, Methanol, 1,1,1-Trichloroethane, Styrene, Phenols	Cd, Hg, Pb, Zn, CN
26	Manufacture of other non-metallic mineral products	BTEX, TPH, PAHs, PCBs, Aliphatic hydrocarbons	B, Cd, Cr, Cu, Hg, Ni, Pb, Zn
26.1	Manufacture of glass and glass products	BTEX, HFCs, PAHs, TPH, VHH, Aliphatic hydrocarbons, Dioxins, Furans	As, B, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, Se, Ti, Tl, Zn
26.21	Manufacture of ceramic household and ornamental articles	BTEX, HFCs, PAHs, PCBs, TPH, Aliphatic hydrocarbons, Dioxins, Furans	As, B, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se, Ti, Tl, Zn
26.4	Manufacture of bricks, tiles and construction products, in baked clay	BTEX, TPH, PAHs, PCBs, Aliphatic hydrocarbons	B, Cd, Cr, Cu, Hg, Ni, Pb, Zn
26.51	Manufacture of cement	BTEX, HFCs, TPH, PAHs, PCBs, Aliphatic hydrocarbons, Dioxins, Furans	As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sb, V, Zn
26.62	Manufacture of plaster products for construction purposes	BTEX, TPH, PAHs, PCBs, Aliphatic hydrocarbons	B, Cd, Cr, Cu, Hg, Ni, Pb, Zn
26.7	Cutting, shaping and finishing of stone	BTEX, TPH, PAHs, PCBs, Aliphatic hydrocarbons	B, Cd, Cr, Cu, Hg, Ni, Pb, Zn
26.8	Manufacture of other non-metallic mineral products	BTEX, HFCs, TPH, PAHs, PCBs, Aliphatic hydrocarbons, Dioxins, Furans	As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sb, V, Zn
27	Manufacture of basic metals	BTEX, PAHs, PCBs, HCB, TPH, Phenols, Dioxins, Furans	As, Cd, Cr, Cu, Hg, Ni, Pb, V, Zn

Table B.1 Soil Contaminants associated with the Industries (Cont'd)

NACE CODE	INDUSTRY	ORGANIC COMPOUNDS	INORGANICS
28.51	Treatment and coating of metals	NMVOC, PAHs, PFCs, Cyanide, Benzene, 1,1,1-Trichloroethane, Dioxins, Furans	As, Cd, Cr, Cu, Hg, Ni, Pb, Zn
29	Manufacture of machinery and equipment n.e.c.	BTEX, PAHs, PCBs, TPH, VHH, Phenols, Chlorophenols, Dioxins, Furans, Aliphatic hydrocarbons, 1,1,1-Trichloroethane, Freon 113, Trichloroethylene, Methyl ethyl ketone, Dichloromethane	As, Cd, Cr, Cu, Hg, Ni, Pb, Zn
30	Manufacture of office machinery and computers	TPH	
31	Manufacture of electrical machinery and apparatus n.e.c.	PCBs	Be, Cd, Hg, Mn, Ni, Pb, Se, Zn
32	Manufacture of radio, television and communication equipment and apparatus	TPH	
33	Manufacture of medical, precision and optical instruments, watches and clocks	TPH	
34	Manufacture of motor vehicles, trailers and semi-trailers	TPH	Cd, Cr, Cu, Hg, Ni, Pb, Zn
35	Manufacture of other transport equipments	BTEX, PAHs, PCBs, TPH, VHH, Biocides, Pesticides, Phenols, Chlorophenols, Aliphatic hydrocarbons, Organotin compounds	As, Cd, Cr, Cu, Hg, Ni, Pb, Sn, Zn
36.1	Manufacture of furniture	BTEX, PAHs, Phenols, Total chlorophenols, Pesticides, Aliphatic hydrocarbons, Organotin compounds	As, Cu, Cr, Hg, Ni, Pb, Zn
37	Recycling		Ag, Cd, Cr, Cu, Hg, Ni, Pb, Zn
40	Electricity, gas, steam and hot water supply	TPH, BTEX	
40.1	Production and distribution of electricity	PAHs, PCBs	As, B, Ba, Cd, Cr, Cu, Hg, Mn, Mo, Pb, Sb, Se, Zn

Table B.1 Soil Contaminants associated with the Industries (Cont'd)

NACE CODE	INDUSTRY	ORGANIC COMPOUNDS	INORGANICS
50.2	Maintenance and repair of motor vehicles	BTEX, MTBE, PAHs, TPH, VHH, aliphatic hydrocarbons, Chlorinated hydrocarbons, Organolead compounds	Ba, Cd, Cr, Cu, Hg, Ni, Pb, Zn
50.5	Retail sale of automotive fuel	BTEX, MTBE, TPH, Aliphatic hydrocarbons, Organolead compounds, Trichloroethylene	Ba, Cu, Cd, Pb, Ni, Zn
51.51	Wholesale of solid, liquid and gaseous fuels and related products	TPH, BTEX	As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sb, V, Zn
51.52	Wholesale of metals and metal ores		Cd, Cu, Cr, Hg, Pb, Zn
51.55	Wholesale of chemical products	TPH	
51.57	Wholesale of waste and scrap	TPH	
60	Land transport; transport via pipelines	TPH, BTEX	
62	Air transport	BTEX, PCBs, TPH, VHH	As, Cd, Hg, Pb
74.81	Photographic activities	BTEX, VHH	As, Cd, Cr, Cu, Hg, Pb, Zn and inorganic compounds
75.22	Defence activities	BTEX, NMVOC, PAHs, PCBs, TPH	As, B, Cd, Cr, Cu, Hg, Ni, Pb, Zn, Asbestos
85.1	Human health activities	BTEX, PCBs, TPH	Ag, As, Ba, Bi, Cd, Cr, Cu, Hg, Mo, Pb, Sb, Se, Sn, Pt, Zn
85.2	Veterinary activities	TPH	Ag, As, Ba, Bi, Cd, Cr, Cu, Hg, Mo, Pb, Pt, Sb, Se, Sn, Zn

Table B.1 Soil Contaminants associated with the Industries (Cont’d)

NACE CODE	INDUSTRY	ORGANIC COMPOUNDS	INORGANICS
90	Sewage and refuse disposal, sanitation and similar activities	BTEX, MTBE, PAHs, PCBs, PCPs, TPH, VHH, Pesticides, Phenols, Chlorophenols, Dioxins, Furans, Aliphatic hydrocarbons, Chlorinated aromatic hydrocarbons, Organolead and Organotin compounds	As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, Se, Zn
93.01	Washing and dry-cleaning of textile and fur products	BTEX, TPH, VHH, Aliphatic hydrocarbons	Cd, Cu, Cr, Hg, Pb, Zn

n.e.c.: not elsewhere classified
DCM: Dichloromethane
HCB: Hexachlorobenzene
HFCs: Hydrofluorocarbons
MTBE: Methyl-Tertiary-Butyl Ether
NMVOC: Non-Methane Volatile Organic Compounds
PAE: Phthalatic Acid Esters (phthalates)
PAHs: Polycyclic Aromatic Hydrocarbons
PCBs: Poly Chlorinated Biphenyls
PCPs: 1-(1-Phencyclohexyl) piperidine
PCPs: 1-(1-Phencyclohexyl) piperidine
PER: Tetrachloroethylene
PFCs: Perfluorocarbons
TCE: Trichloroethane-1,1,1
TCM: Tetrachloromethane
TPH: Total Petroleum Hydrocarbons
TRI: Trichloroethylene
VHH: Volatile Halogenated Hydrocarbons (Trichloromethane, etc.)

Table B.2 The Soil Contaminants included in the Regulations of Other Countries

	US EPA	**Germany**	**France**	**Netherlands**	**Spain**	**Canada**	**Norway**
AROMATIC HYDROCARBONS							
BTEX		+					
Benzene	+	+	+	+	+	+	+
Ethylbenzene	+		+	+	+	+	+
Styrene	+		+	+	+	+	
Toluene	+		+	+	+	+	+
Xylenes	+		+	+	+	+	+
POLYCYCLIC AROMATIC HYDROCARBONS							
Acenaphtene	+						
Anthracane	+				+		
Benzo(a)anthracane	+		+		+	+	
Benzo(a)pyrene	+	+	+		+	+	+
Benzo(b)fluoranthene	+				+	+	
Benzo(k)fluoranthene	+		+		+	+	
Chrysene	+		+		+		
Dibenz(a,h)anthracene	+				+	+	
Fluoranthene	+		+		+		+
Indeno(1,2,3-c,d)pyrene	+		+		+	+	
Naphtalene	+	+	+		+	+	+
PAH total		+		+			+
Phenanthrene						+	
Pyrene	+				+	+	+
HALOGENATED ALIPHATIC HYDROCARBONS							
Aliphatics C5-C6							+
Aliphatics >C6-C8							+
Aliphatics >C8-C10							+
Aliphatics >C10-C12							+
Aliphatics >C12-C16							+
Aliphatics >C16-C35							+
Bromodichloromethane	+						
1,2-Bromoethane							+
Bromoform (tribronomethane)	+			+			
Chlorinated aliphatics						+	
Chlorodibromomethane (Dibromochloromethane)	+						
Chloroethene (vinyl chloride)	+		+		+		
Chloroform	+		+	+	+		+
1,1-Dichloroethane	+			+	+		
1,1-Dichloroethylene	+				+		
1,2-Dichloroethane	+		+	+	+		+
1,2-Dichloroethylene(cis)	+		+				
1,2-Dichloroethylene(trans)	+						
Dichloromethane			+	+			+
1,2-Dichloropropane	+		+		+		
1,3-Dichloropropene	+			+	+		

Table B.2 The Soil Contaminants included in the Regulations of Other Countries (cont'd)

	US EPA	**Germany**	**France**	**Netherlands**	**Spain**	**Canada**	**Norway**
Hexachlorobutadiene	+				+		
Hexachloroethane	+				+		
Methyl bromide	+						
1,1,2,2-Tetrachloroethane	+				+		
Tetrachloroethene				+	+		
Tetrachloroethylene	+		+			+	+
Tetrachloromethane			+	+			
1,1,1-Trichloroethane	+		+	+	+		+
1,1,2-Trichloroethane	+			+			
Trichloroethylene	+		+	+	+	+	+
HALOGENATED AROMATIC HYDROCARBONS							
Chlorobenzene	+		+	+	+	+	+
1,2-Dichlorobenzene	+		+		+	+	+
1,3-Dichlorobenzene			+			+	
1,4-Dichlorobenzene	+		+		+	+	+
Hexachlorobenzene	+	+	+		+	+	+
Hexachlorocyclopentadiene	+						
Pentachlorobenzene							+
1,2,4,5-Tetrachlorobenzene							+
1,2,4-Trichlorobenzene	+		+		+		+
Total tri- and, tetra- and penta-chlorobenzenes						+	
HALOGENATED POLYCYCLIC HYDROCARBONS							
Arochlor 1016			+				
Arochlor 1254			+				
p-Chloroaniline	+						
Chloronaphtalene			+				
Dioxins, furans planar PCBs		+					
Monochloroaniline				+			
PCB		+		+	+	+	+
PCDD/PCDF			+			+	
PESTICIDES							
Aldrin	+	+	+	+	+		
Atrazine			+	+			
Carbaryl			+	+			
Carbofurane			+	+			
Chlorodane	+			+	+		
DDD	+						
DDD,DDE,DDT total			+	+		+	
DDE	+						
DDT	+	+			+		+
Dieldrin	+			+	+		
2,4-Dichlorophenoxyacetic acid	+						
Drines total			+	+			
Endosulfan	+			+	+		

Table B.2 The Soil Contaminants included in the Regulations of Other Countries (cont’d)

	US EPA	**Germany**	**France**	**Netherlands**	**Spain**	**Canada**	**Norway**
Endrin	+			+	+		
HCH total		+	+	+			
α-HCH	+						
β-HCH	+						
γ-HCH (Lindane)	+						+
Heptachlore and epoxyde of heptachlore	+			+			
Heptachlor	+			+			
Maneb			+	+			
MCPA				+			
Organotin compounds				+			
KETONS							
Acetone	+						
Cyclohexanone				+			
Isophorone	+						
PHENOLS AND CHLOROPHENOLS							
Catechol			+	+			
2-Chlorophenol	+				+		
Chlorophenols total			+	+		+	
Cresols total			+	+			
o-Cresol (2-Methylphenol)	+				+		
2,4-Dichlorophenol	+				+		
2,4-Dimethylphenol	+						
2,4-Dinitrophenol	+						
Hydroquinone			+	+			
Nonchlorinated phenols						+	
Pentachlorophenol	+	+	+		+	+	+
Phenol	+	+	+	+	+	+	
Resorcinol			+	+			
2,4,5-Trichlorophenol	+				+		
2,4,6-Trichlorophenol	+				+		
PHTHALATES							
Bis(2-ethylhexyl)phthalate		+					
Butyl benzyl phthalate		+					
Di(2-ethylhexyl)Phthalate	+						
Di-n-butyl phthalate	+						
Di-n-octyl phthalate	+						
Phthalates total			+	+			
ORGANIC NITROGEN COMPOUNDS							
Acrylamide			+				
Carbazole	+						
2,4-Dinitrotoluene	+						
2,6-Dinitrotoluene	+						
3,3-Dichlorobenzidine	+						
Nitrobenzene	+						
N-Nitrosodi propylamine	+						
N-Nitrosodiphenylamine	+						

Table B.2 The Soil Contaminants included in the Regulations of Other Countries (cont'd)

	US EPA	**Germany**	**France**	**Netherlands**	**Spain**	**Canada**	**Norway**
OTHER ORGANICS							
Benzoic acid	+						
Bis(2-chloroethyl)ether	+						
Butanol	+						
Carbon disulfide	+						
Carbon tetrachloride	+						
Hydrocarbons			+				
Methoxychlor	+						
Methylene chloride	+						
Mineral oil		+		+			
MTBE							+
Pyridine				+			
Tetrahydrofuran				+			
Tetrahydrothiophene				+			
Toxaphene	+						
Vinyl acetate	+						
METALS							
Antimony	+	+	+	+		+	
Arsenic	+	+	+	+		+	+
Barium	+		+	+		+	
Beryllium	+		+			+	
Cadmium	+	+	+	+		+	+
Chromate		+					
Chromium (total)	+	+	+	+		+	+
Chromium (III)	+						
Chromium (VI)	+	+					
Cobalt		+	+	+		+	
Copper		+	+	+		+	+
Lead		+	+	+		+	+
Mercury	+	+	+	+		+	+
Molybdenum		+	+	+		+	
Nickel	+	+	+	+		+	+
Selenium	+	+				+	
Silver	+					+	
Thallium	+	+	+			+	
Tin		+					
Vanadium	+		+			+	
Zinc	+	+	+	+		+	+
OTHER INORGANICS							
Bromides				+			
Cyanides,(amenable)	+						
Cyanides,free		+	+	+		+	+
Cyanides-complex(pH<5)				+			
Cyanides-complex(pH>=5)				+			

Table B.2 The Soil Contaminants included in the Regulations of Other Countries (cont'd)

	US EPA	**Germany**	**France**	**Netherlands**	**Spain**	**Canada**	**Norway**
Total cyanide		+					
Thiocyanates (sum)				+			
Tetraethyllead							+
Fluorene	+						+
Flourides		+		+		+	

* References used for preparation of this table include US EPA, 2002a; Federal Ministry of Environment, 1999a; Darmendrail D., 2003; VROM, 2000; Ministry of the Presidency, 2005; CCME, 2001; SFT, 1999.

APPENDIX-C

EXAMPLE CALCULATIONS FOR SQSs

1. CALCULATION OF SQSs FOR BENZENE FOR RESIDENTIAL LAND USE

SQS FOR INGESTION - DERMAL ABSORPTION PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$IF_{soil/adj} = \left[\frac{IR_{soil/1\text{-}6} \times ED_{1\text{-}6}}{BW_{1\text{-}6}}\right] + \left[\frac{IR_{soil/7\text{-}31} \times ED_{7\text{-}31}}{BW_{7\text{-}31}}\right] \qquad (2.7)$$

$$IF_{soil/adj} = \frac{200 \times 6}{15} + \frac{100 \times 24}{70} = 114 \ \frac{mg\text{-}yr}{kg\text{-}day}$$

$IF_{soil/adj}$ (age-adjusted soil ingestion factor)	-	mg-year/kg-day
$IR_{soil/1\text{-}6}$ (ingestion rate of soil age 1-6)	200	mg/day
$IR_{soil/7\text{-}31}$ (ingestion rate of soil age 7-31)	100	mg/day
$ED_{1\text{-}6}$ (exposure duration during ages 1-6)	6	year
$ED_{7\text{-}31}$ (exposure duration during ages 7-31)	24	year
$BW_{1\text{-}6}$ (average body weight from ages 1-6)	15	kg
$BW_{7\text{-}31}$ (average body weight from ages 7-31)	70	kg

$$SF_{ABS} = \frac{SF_o}{ABS_{GI}} \qquad (2.9)$$

$$SF_{ABS} = \frac{5.5 \times 10^{-2}}{1} = 5.5 \times 10^{-2} (mg/kg\text{-}day)^{-1}$$

SF_{ABS} (dermally adjusted slope factor)	-	$(mg/kg\text{-}day)^{-1}$
SF_o (oral slope factor)	5.5×10^{-2}	$(mg/kg\text{-}day)^{-1}$
ABS_{GI} (gastro-intestinal absorption factor)	1	unitless

$$SFS = \left[\frac{SA_{1-6} \times AF_{1-6} \times ED_{1-6}}{BW_{1-6}}\right] + \left[\frac{SA_{7-31} \times AF_{7-31} \times ED_{7-31}}{BW_{7-31}}\right] \qquad (2.8)$$

$$\text{SFS} = \left[\frac{2800 \times 0.2 \times 6}{15}\right] + \left[\frac{5700 \times 0.07 \times 24}{70}\right] = 360 \ mg\text{-}yr/kg\text{-}event$$

SFS (age-adjusted dermal factor)	-	mg-year/kg-event
SA_{1-6} (skin surface area exposed-child)	2800	cm^2
SA_{7-31} (skin surface area exposed-adult)	5700	cm^2
AF_{1-6} (skin-soil adherence factor-child)	0.2	mg/cm^2-event
AF_{7-31} (skin-soil adherence factor-adult)	0.07	mg/cm^2-event
ED_{1-6} (exposure duration-child)	6	year
ED_{7-31} (exposure duration-adult)	24	year
BW_{1-6} (body weight-child)	15	kg
BW_{7-31} (body weight-adult)	70	kg

$$SQS_1^c \ (mg/kg) = \frac{TR \times AT \times 365 \ d/yr}{\left(EF \times 10^{-6} \ kg/mg\right)\left[(SF_o \times IF_{soil/adj}) + (SF_{ABS} \times SFS \times ABS_d \times EV)\right]} \qquad (2.6)$$

$$SQS_1^c = \frac{10^{-6} \times 70 \times 365}{350 \times 10^{-6} \times \left[\left(5.5 \times 10^{-2} \times 114\right) + \left(5.5 \times 10^{-2} \times 360 \times 0 \times 1\right)\right]} \cong 12 \ mg/kg$$

SQS_1^c (carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
EF (exposure frequency)	350	day/year
SF_{ABS} (dermally adjusted cancer slope factor)	5.5×10^{-2}	$(mg/kg\text{-}day)^{-1}$
SFS (age-adjusted dermal factor)	360	mg-year/kg-event
ABS_d (dermal absorption factor)	- *	unitless
EV (event frequency)	1	event/day
SF_o (oral slope factor)	5.5×10^{-2}	$(mg/kg\text{-}day)^{-1}$
$IF_{soil/adj}$ (age-adjusted soil ingestion factor)	114	mg-year/kg-day

* Only *SQS* for ingestion of soil can be estimated, since ABS_d for benzene does not exist.

Calculation of SQS for Non-Carcinogenic Effects:

$$RfD_{ABS}=RfD_o\times ABS_{GI} \qquad (2.11)$$

$$RfD_{ABS}=\left(4\times 10^{-3}\right)\times(1)=4\times 10^{-3}mg/kg\text{-}day$$

RfD_{ABS} (dermally-adjusted reference dose)	-	mg/kg-day
RfD_o (oral reference dose)	4×10^{-3}	mg/kg-day
ABS_{GI} (gastro-intestinal absorption factor)	1	unitless

$$SQS_1^{nc}=\frac{THQ\times BW\times AT\times 365\ d/yr}{\left(EF\times ED\times 10^{-6}kg/mg\right)\Big[\left(\frac{1}{RfD_o}\times IR\right)+\left(\frac{1}{RfD_{ABS}}\times AF\times ABS_d\times EV\times SA\right)} \qquad (2.10)$$

$$SQS_1^{nc}=\frac{1\times 15\times 6\times 365\ d/yr}{\left(350\times 6\times 10^{-6}\right)\left[\left(\frac{1}{4\times 10^{-3}}\times 200\right)+\left(\frac{1}{4\times 10^{-3}}\times 0.2\times 0\times 1\times 2800\right)\right]}=313\ mg/kg$$

SQS_1^{nc} (non-carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
THQ (target hazard quotient)	1	unitless
BW (body weight)	15	kg
AT (averaging time)	6	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	6	year
RfD_o (oral reference dose)	4×10^{-3}	mg/kg-day
IR (soil ingestion rate)	200	mg/day
RfD_{ABS} (dermally-adjusted reference dose)	4×10^{-3}	mg/kg-day
AF (skin-soil adherence factor)	0.2	mg/cm^2-event
ABS_d (dermal absorption factor)	-	unitless
EV (event frequency)	1	event/day
SA (skin surface area exposed-child)	2800	cm^2

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF BENZENE

SQS_1^c calculated considering carcinogenic risks	12 mg/kg
SQS_1^{nc} calculated considering non-carcinogenic effects	313 mg/kg
SQS_1 for ingestion-dermal absorption pathway	**12 mg/kg**

SQS FOR INHALATION OF FUGITIVE PARTICULATES PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$PEF=Q/C_{wind}\times\frac{3600\ s/h}{0.036\times(1-V)\times(U_m/U_t)^3\times F(x)} \qquad (2.14)$$

$$PEF=59.24\times\frac{3600}{0.036\times(1-0.2)\times(3.0/8.28)^3\times(6.67\times10^{-2})}=2.33\times10^{9}\ m^3/k$$

PEF (particulate emission factor)	-	m^3/kg
Q/C_{wind} (air dispersion factor for fugitive dusts)	59.24	$(g/m^2\text{-}s)\ /\ (kg/m^3)$
V (fraction of continuous vegetative cover)	0.2	unitless
U_m (mean annual wind speed)	3.0	m/s
U_t (equivalent threshold value of wind speed at 10 m)	8.28	m/s
F(x) (Function dependent on U_m/U_t derived using Cowherd et al.)	6.67×10^{-2}	unitless

$$SQS_2^c=\frac{TR\times AT\times 365\ d/yr}{URF\times EF\times ED\times\left[\frac{1}{PEF}\right]} \qquad (2.12)$$

$$SQS_2^c=\frac{10^{-6}\times70\times365}{7.8\times10^{-3}\times350\times30\times\left[\frac{1}{2.33\times10^{9}}\right]}=726{,}880\ mg/kg$$

SQS_2^c (carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	7.8×10^{-3}	$(mg/m^3)^{-1}$
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
PEF (particulate emission factor)	2.33×10^{9}	m^3/kg

Calculation of SQS for Non-Carcinogenic Effects:

$$SQS_2^{nc}=\frac{THQ\times AT\times 365\ d/yr}{EF\times ED\times\left(\frac{1}{RfC}\times\frac{1}{PEF}\right)} \tag{2.13}$$

$$SQS_2^{c}=\frac{1\times 30\times 365}{350\times 30\times\left(\frac{1}{3.0\times 10^{-2}}\times\frac{1}{2.33\times 10^{9}}\right)}= 72{,}895{,}714\ mg/kg$$

SQS_2^{nc} (non-carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfC (inhalation reference concentration)	$3.0\text{x}10^{-2}$	mg/m^3
PEF (particulate emission factor)	$2.33\text{x}10^{9}$	m^3/kg

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF BENZENE

SQS_2^{c} calculated considering carcinogenic risks	726,880 mg/kg
SQS_2^{nc} calculated considering non-carcinogenic effects	72,895,714 mg/kg
SQS_2 for inhalation of fugitive particulates pathway	**726,880 mg/kg**

As can be seen above, SQS_2 calculated for inhalation of fugitive particulates pathway is quite higher than SQS_1 calculated for ingestion-dermal absorption pathway. Because of this reason, SQS_1 for ingestion-dermal absorption pathway is found to be sufficient for protection of human health. As a result, it is not necessary to calculate SQS_2^{c} and SQS_2^{nc} for organic compounds.

SQS FOR INHALATION OF VOLATILE CONTAMINANTS PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$D_A=\frac{\left[\left(\theta_a^{10/3}D_iH^{'}+\theta_w^{10/3}D_w\right)/n^2\right]}{\rho_bK_d+\theta_w+\theta_aH^{'}} \qquad (2.18)$$

$$D_A=\frac{\left[\left(0.28^{10/3}\right)\times\left(8.95\times10^{-2}\right)\times\left(2.27\times10^{-1}\right)+\left(0.15^{10/3}\right)\times\left(1.03\times10^{-5}\right)\right]/0.43^2}{(1.5)\times\left(1.46\times10^2)\times(0.006\right)+(0.15)+(0.28)\times\left(2.27\times10^{-1}\right)}$$

$$D_A=1.03\times10^{-3}cm^2/s$$

$$VF=\frac{Q/C_{vol}\times(3.14\times D_A\times T)^{1/2}\times\left(10^{-4}\ m^2/cm^2\right)}{(2\times\rho_b\times D_A)} \qquad (2.17)$$

$$VF=\frac{27.61\times\left[3.14\times\left(9.24\times10^{-4}\right)\times\left(9.5\times10^8\right)\right]^{1/2}\times10^{-4}}{2\times1.5\times\left(9.24\times10^{-4}\right)}=1654\ m^3/kg$$

VF (soil to air volatilization factor)	-	m^3/kg
D_A (apparent diffusivity)	-	cm^2/s
Q/C_{vol} (air dispersion factor for volatiles)	27.61	$(g/m^2.s)/(kg/m^3)$
T (exposure interval)	$9.5x10^8$	s
ρ_b (dry soil bulk density)	1.5	g/cm^3
θ_a (air filled soil porosity)	0.28	cm^3/cm^3
n (total soil porosity)	0.43	cm^3/cm^3
θ_w (water filled soil porosity)	0.15	cm^3/cm^3
ρ_s (soil particle density)	2.65	g/cm^3
D_i (diffusivity in air)	$8.95x10^{-2}$	cm^2/s
$H^{'}$ (Henry's law constant)	$2.27x10^{-1}$	unitless
D_w (diffusivity in water)	$1.03x10^{-5}$	cm^2/s
K_d (soil-water partition coefficient)	$K_d=K_{oc}\times f_{oc}$	cm^3/g
K_{oc} (soil organic carbon partition coefficient)	$1.46x10^2$	cm^3/g
f_{oc} (fraction of organic carbon in soil)	0.006	g/g

$$SQS_3^c = \frac{TR \times AT \times 365\ d/yr}{URF \times EF \times ED \times \left(\frac{1}{VF}\right)} \tag{2.15}$$

$$SQS_3^c = \frac{10^{-6} \times 70 \times 365}{\left(7.8 \times 10^{-3}\right) \times 350 \times 30 \times \left(\frac{1}{1654}\right)} \cong 0.5\ mg/kg$$

SQS_3^c (carcinogenic SQS for inhalation of volatile contaminants)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	$7.8\text{x}10^{-3}$	$(mg/m^3)^{-1}$
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
VF (soil to air volatilization factor)	1654	m^3/kg

Calculation of SQS for Non-Carcinogenic Effects:

$$SQS_3^{nc} = \frac{THQ \times AT \times 365\ d/yr}{EF \times ED \times \left(\frac{1}{RfC} \times \frac{1}{VF}\right)} \tag{2.16}$$

$$SQS_3^{nc} = \frac{1 \times 30 \times 365}{350 \times 30 \times \left(\frac{1}{3.0 \times 10^{-2}} \times \frac{1}{1654}\right)} = 52\ mg/kg$$

SQS_3^{nc} (non-carcinogenic SQS for inhalation of volatile contaminants)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfC (inhalation reference concentration)	$3.0\text{x}10^{-2}$	mg/m^3
VF (soil to air volatilization factor)	1654	m^3/kg

Soil Saturation Concentration:

$$C_{sat}=\frac{S}{\rho_b}\left[K_d\rho_b+\theta_w+H'\theta_a\right] \tag{2.19}$$

$$C_{sat}=\frac{1.79\times10^3}{1.5}\left[1.46\times10^2\times0.006\times1.5+0.15+2.27\times10^{-1}\times0.28\right]=1823\ mg/kg$$

C_{sat} (soil saturation concentration)	-	mg/kg
S (solubility in water)	$1.79\text{x}10^3$	mg/L
ρ_b (dry soil bulk density)	1.5	kg/L
K_d (soil-water partition coefficient)	$K_d=K_{oc}\times f_{oc}$	L/kg
K_{oc} (soil organic carbon partition coefficient)	$1.46\text{x}10^2$	L/kg
f_{oc} (fraction of organic carbon in soil)	0.006 (%0.6)	g/g
θ_w (water filled soil porosity)	0.15	cm^3/cm^3
H' (Henry's law constant)	$2.27\text{x}10^{-1}$	unitless
θ_a (air filled soil porosity)	0.28	cm^3/cm^3
n (total soil porosity)	0.43	cm^3/cm^3
ρ_s (soil particle density)	2.65	g/cm^3

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF BENZENE

SQS_3^c calculated considering carcinogenic risks	0.5 mg/kg
SQS_3^{nc} calculated considering non-carcinogenic effects	52 mg/kg
Soil saturation concentration, C_{sat}	1823 mg/kg
SQS_3 for inhalation of volatile contaminants pathway	**0.5 mg/kg**

SQS FOR MIGRATION TO GROUNDWATER PATHWAY

$$SQS_4 = C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right) \tag{2.20}$$

$$SQS_4 = 1.0\times10^{-3}\left(1.46\times10^{2}\times0.002 + \frac{0.3+0.13\times2.27\times10^{-1}}{1.5}\right) = 5\times10^{-4}\ mg/kg$$

$\boldsymbol{SQS_4}$ (SQS for migration to groundwater pathway)	-	mg/kg
$\boldsymbol{C_w}$ (target soil leachate concentration)	1.0×10^{-3} (TS-266)*	mg/L
$\boldsymbol{K_d}$ (soil-water partition coefficient)	$K_d=K_{oc}\times f_{oc}$	L/kg
$\boldsymbol{K_{oc}}$ (soil organic carbon partition coefficient)	1.46×10^{2}	L/kg
$\boldsymbol{f_{oc}}$ (fraction of organic carbon in soil)	0.002 (% 0.2)	g/g
$\boldsymbol{\theta_w}$ (water filled soil porosity)	0.3	cm^3/cm^3
$\boldsymbol{\theta_a}$ (air filled soil porosity)	0.13	cm^3/cm^3
$\boldsymbol{H'}$ (Henry's law constant)	2.27×10^{-1}	unitless
$\boldsymbol{n}$ (total soil porosity)	0.43	cm^3/cm^3
$\boldsymbol{\rho_b}$ (dry soil bulk density)	1.5	kg/L
$\boldsymbol{\rho_s}$ (soil particle density)	2.65	kg/L

* *DF* is taken as 1.

COMPARISION OF SQS WITH C_{sat}

SQS_4 calculated	0.0005 mg/kg
Soil saturation concentration, C_{sat}	1823 mg/kg
SQS_4 for migration to groundwater pathway	**0.0005 mg/kg**

SQSs CALCUATED FOR BENZENE

1. Ingestion-dermal absorption pathway	12 mg/kg
2. Inhalation of fugitive particulates pathway	-
3. Inhalation of volatile contaminants pathway	0.5 mg/kg
4. Migration to groundwater pathway	0.0005 mg/kg

2. CALCULATION OF SQSs FOR COBALT FOR RESIDENTIAL LAND USE

SQS FOR INGESTION - DERMAL ABSORPTION PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$SQS_1^c\ (mg/kg)=\frac{TR\times AT\times 365\,d/yr}{\left(EF\times 10^{-6}\,kg/mg\right)\left[\left(SF_o\times IF_{soil/adj}\right)+\left(SF_{ABS}\times SFS\times ABS_d\times EV\right)\right]} \qquad (2.6)$$

SQS_1^c (carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
EF (exposure frequency)	350	day/year
SF_{ABS} (dermally adjusted cancer slope factor)	- *	$(mg/kg\text{-}day)^{-1}$
SFS (age-adjusted dermal factor)	360	mg-year/kg-event
ABS_d (dermal absorption factor)	$1.0x10^{-3}$	unitless
EV (event frequency)	1	event/day
SF_o (oral slope factor)	- *	$(mg/kg\text{-}day)^{-1}$
$IF_{soil/adj}$ (age-adjusted soil ingestion factor)	114	mg-year/kg-day

* Since SF_o does not exist for cobalt, SQS_1^c cannot be calculated.

Calculation of SQS for Non-Carcinogenic Effects:

$$RfD_{ABS}=RfD_o\times ABS_{GI} \qquad (2.11)$$

$$RfD_{ABS}=\left(3\times 10^{-4}\right)\times(1)=3\times 10^{-4}\,mg/kg\text{-}day$$

RfD_{ABS} (dermally-adjusted reference dose)	-	mg/kg-day
RfD_o (oral reference dose)	$3.0x10^{-4}$	mg/kg-day
ABS_{GI} (gastro-intestinal absorption factor)	1	unitless

$$SQS_1^{nc} = \frac{THQ \times BW \times AT \times 365\ d/yr}{\left(EF \times ED \times 10^{-6} kg/mg\right)\left[\left(\frac{1}{RfD_o} \times IR\right) + \left(\frac{1}{RfD_{ABS}} \times AF \times ABS_d \times EV \times SA\right)\right]} \quad (2.10)$$

$$SQS_1^{nc} = \frac{1 \times 15 \times 6 \times 365\ d/yr}{\left(350 \times 6 \times 10^{-6}\right)\left[\left(\frac{1}{3 \times 10^{-4}} \times 200\right) + \left(\frac{1}{3 \times 10^{-4}} \times 0.2 \times 0 \times 1 \times 2800\right)\right]} = 23 mg/kg$$

SQS_1^{nc} (non-carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
THQ (target hazard quotient)	1	unitless
BW (body weight)	15	kg
AT (averaging time)	6	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	6	year
RfD_o (oral reference dose)	$3x10^{-4}$	mg/kg-day
IR (soil ingestion rate)	200	mg/day
RfD_{ABS} (dermally-adjusted reference dose)	$3x10^{-4}$	mg/kg-day
AF (skin-soil adherence factor)	0.2	mg/cm^2-event
ABS_d (dermal absorption factor)	-	unitless
EV (event frequency)	1	event/day
SA (skin surface area exposed-child)	2800	cm^2

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF CADMIUM

SQS_1^c calculated considering carcinogenic risks	-
SQS_1^{nc} calculated considering non-carcinogenic effects	23 mg/kg
SQS_1 for ingestion-dermal absorption pathway	**23 mg/kg**

SQS FOR INHALATION OF FUGITIVE PARTICULATES PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$PEF=Q/C_{wind}\times\frac{3600\ s/h}{0.036\times(1-V)\times(U_m/U_t)^3\times F(x)} \tag{2.14}$$

$$PEF=59.24\times\frac{3600}{0.036\times(1-0.2)\times(3.0/8.28)^3\times6.67\times10^{-2}}=2.33\times10^9\ m^3/kg$$

PEF (particulate emission factor)	-	m^3/kg
***Q/C**$_{wind}$* (air dispersion factor for fugitive dusts)	59.24	$(g/m^2\text{-}s)/(kg/m^3)$
V (fraction of continuous vegetative cover)	0.2	unitless
***U**$_m$* (mean annual wind speed)	3.0	m/s
***U**$_t$* (equivalent threshold value of wind speed at 10m)	8.28	m/s
F(x) (Function dependent on U_m/U_t derived using Cowherd et al.)	6.67×10^{-2}	unitless

$$SQS_2^c=\frac{TR\times AT\times365\ d/yr}{URF\times EF\times ED\times\left[\frac{1}{PEF}\right]} \tag{2.12}$$

$$SQS_2^c=\frac{10^{-6}\times70\times365}{9\times350\times30\times\left[\frac{1}{2.33\times10^9}\right]}=631\ mg/kg$$

$\boldsymbol{SQS_2^c}$ (carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	9	$(mg/m^3)^{-1}$
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
PEF (particulate emission factor)	2.33×10^9	m^3/kg

Calculation of SQS for Non-Carcinogenic Effects:

$$SQS_2^{nc} = \frac{THQ \times AT \times 365\ d/yr}{EF \times ED \times \left(\frac{1}{RfC} \times \frac{1}{PEF}\right)} \tag{2.13}$$

$$SQS_2^{nc} = \frac{1 \times 30 \times 365\ d/yr}{350 \times 30 \times \left(\frac{1}{6 \times 10^{-6}} \times \frac{1}{2.33 \times 10^{9}}\right)} = 14{,}579\ mg/kg$$

SQS_2^{nc} (non-carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30	year
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfC (inhalation reference concentration)	$6x10^{-6}$	mg/m^3
PEF (particulate emission factor)	$2.33x10^9$	m^3/kg

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF CADMIUM

SQS_2^{c} calculated considering carcinogenic risks	631 mg/kg
SQS_2^{nc} calculated considering non-carcinogenic effects	14,579 mg/kg
SQS_2 for inhalation of fugitive particulates pathway	**631 mg/kg**

SQS FOR INHALTION OF VOLATILE CONTAMINANTS PATHWAY

Since inorganic compounds are not volatile, SQSs are not calculated for compounds other than mercury for inhalation of volatile contaminants pathway.

SQS FOR MIGRATION TO GROUNDWATER PATHWAY

Since there exist no TS-266 and WHO standards for cobalt, it is necessary to calculate health based limit (*HBL*).

$$HBL^{c}(mg/L)=\frac{TR\times AT\times 365\,d/yr}{EF\times SF_{O}\times IF_{w\text{-}adj}} \tag{2.21}$$

HBL^{c} (carcinogenic health based limit)	-	mg/L
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
EF (exposure frequency)	350	day/year
SF_{o} (oral slope factor)	- *	$(mg/kg\text{-}day)^{-1}$
$IF_{w\text{-}adj}$ (age-adjusted drinking water ingestion rate)	1.086	L-year/kg-day

* Since SF_{O} does not exist for cobalt, HBL^{c} cannot be calculated.

$$HBL^{nc}(mg/L)=\frac{THQ\times AT\times BW\times 365\,d/yr}{EF\times ED\times \frac{1}{RfD_{O}}\times IR_{W}} \tag{2.23}$$

$$HBL^{nc}(mg/L)=\frac{1\times 30\times 70\times 365}{350\times 30\times \frac{1}{3\times 10^{-4}}\times 2}=1.1\times 10^{-2}\ mg/L$$

HBL^{nc}(non-carcinogenic health based limit)	-	mg/L
THQ (target hazard quotient)	1	unitless
AT (averaging time)	30	year
BW (body weight)	70	kg
EF (exposure frequency)	350	day/year
ED (exposure duration)	30	year
RfD_{o} (oral reference dose)	$3x10^{-4}$	mg/kg-day
IR_{W} (drinking water ingestion rate)	2	L/day

$$SQS_4 = C_w\left(K_d + \frac{\theta_w + \theta_a H^{'}}{\rho_b}\right) \tag{2.20}$$

$$SQS_4 = 1.1\times10^{-2}\left(4.5\times10^{1} + \frac{0.3+0.13\times0}{1.5}\right) = 0.5\ mg/kg$$

SQS_4 (SQS for migration to groundwater pathway)	-	mg/kg
C_w (target soil leachate concentration)	$1.1\text{x}10^{-2}$ (*HBL*)*	mg/L
K_d (soil-water partition coefficient)	$4.5\text{x}10^{1}$	L/kg
K_{oc} (soil organic carbon partition coefficient)	-	L/kg
f_{oc} (fraction of organic carbon in soil)	0.002 (% 0.2)	g/g
θ_w (water filled soil porosity)	0.3	cm^3/cm^3
θ_a (air filled soil porosity)	0.13	cm^3/cm^3
$H^{'}$ (Henry's law constant)	-	unitless
n (total soil porosity)	0.43	cm^3/cm^3
ρ_b (dry soil bulk density)	1.5	kg/L
ρ_s (soil particle density)	2.65	kg/L

* *DF* is taken as 1.

COMPARISION OF SQS WITH C_{sat}	
SQS_4 calculated	0.5 mg/kg
Soil saturation concentration, C_{sat}	-
SQS_4 for migration to groundwater pathway	**0.5 mg/kg**

***SQSs* CALCUATED FOR COBALT**	
1. Ingestion-dermal absorption pathway	23 mg/kg
2. Inhalation of fugitive particulates pathway	631 mg/kg
3. Inhalation of volatile contaminants pathway	-
4. Migration to groundwater pathway	0.5 mg/kg

3. CALCULATION OF SQSs FOR CARBON TETRACHLORIDE FOR COMMERCIAL/ INDUSTRIAL LAND USE: OUTDOOR WORKER

SQS FOR INGESTION - DERMAL ABSORPTION PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$IF_{soil/adj}=\left[\frac{IR\times ED}{BW}\right] \tag{2.7}$$

$$IF_{soil/adj}=\frac{100\times 25}{70}=35\ \frac{mg\text{-}yr}{kg\text{-}day}$$

$IF_{soil/adj}$ (soil ingestion factor)	-	mg-year/kg-day
IR_{soil} (ingestion rate of soil)	100	mg/day
ED (exposure duration)	25	year
BW (average body weight)	70	kg

$$SF_{ABS}=\frac{SF_o}{ABS_{GI}} \tag{2.9}$$

$$SF_{ABS}=\frac{1.3\times 10^{-1}}{1}=1.3\times 10^{-1}(mg/kg\text{-}day)^{-1}$$

SF_{ABS} (dermally adjusted slope factor)	-	$(mg/kg\text{-}day)^{-1}$
SF_o (oral slope factor)	$1.3x10^{-1}$	$(mg/kg\text{-}day)^{-1}$
ABS_{GI} (gastro-intestinal absorption factor)	1	unitless

$$SFS=\left[\frac{SA\times AF\times ED}{BW}\right] \tag{2.8}$$

$$\text{SFS}=\left[\frac{3300\times 0.2\times 25}{70}\right]=236\ mg\text{-}yr/kg\text{-}event$$

SFS (dermal factor)	-	mg-year/kg-event
SA (skin surface area exposed)	3300	cm^2
AF (skin-soil adherence factor)	0.2	mg/cm^2-event
ED (exposure duration)	25	year
BW (body weight)	70	kg

$$SQS_1^c\ (mg/kg)=\frac{TR\times AT\times 365\,d/yr}{\left(EF\times 10^{-6}\,kg/mg\right)\left[\left(SF_o\times IF_{soil/adj}\right)+\left(SF_{ABS}\times SFS\times ABS_d\times EV\right)\right]} \tag{2.6}$$

$$SQS_1^c=\frac{10^{-6}\times 70\times 365}{225\times 10^{-6}\times\left[\left(1.3\times 10^{-1}\times 35\right)+\left(1.3\times 10^{-1}\times 236\times 0\times 1\right)\right]}=24\ mg/kg$$

$\boldsymbol{SQS_1^c}$ (carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
EF (exposure frequency)	225	day/year
$\boldsymbol{SF_{ABS}}$ (dermally adjusted cancer slope factor)	1.3×10^{-1}	$(mg/kg\text{-}day)^{-1}$
SFS (dermal factor)	236	mg-year/kg-event
$\boldsymbol{ABS_d}$ (dermal absorption factor)	- *	unitless
EV (event frequency)	1	event/day
$\boldsymbol{SF_o}$ (oral slope factor)	1.3×10^{-1}	$(mg/kg\text{-}day)^{-1}$
$\boldsymbol{IF_{soil/adj}}$ (soil ingestion factor)	35	mg-year/kg-day

* Only *SQS* for ingestion of soil can be estimated, since ABS_d for carbon tetrachloride does not exist.

Calculation of SQS for Non-Carcinogenic Effects:

$$RfD_{ABS}=RfD_o\times ABS_{GI} \tag{2.11}$$

$$RfD_{ABS}=\left(7\times 10^{-4}\right)\times(1)=7\times 10^{-4}mg/kg\text{-}day$$

$\boldsymbol{RfD_{ABS}}$ (dermally-adjusted reference dose)	-	mg/kg-day
$\boldsymbol{RfD_o}$ (oral reference dose)	7×10^{-4}	mg/kg-day
$\boldsymbol{ABS_{GI}}$ (gastro-intestinal absorption factor)	1	unitless

$$SQS_1^{nc}=\frac{THQ\times BW\times AT\times 365\ d/yr}{\left(EF\times ED\times 10^{-6}kg/mg\right)\left[\left(\frac{1}{RfD_o}\times IR\right)+\left(\frac{1}{RfD_{ABS}}\times AF\times ABS_d\times EV\times SA\right)\right.} \quad (2.10)$$

$$SQS_1^{nc}=\frac{1\times 70\times 25\times 365\ d/yr}{\left(225\times 25\times 10^{-6}\right)\left[\left(\frac{1}{7\times 10^{-4}}\times 100\right)+\left(\frac{1}{7\times 10^{-4}}\times 0.2\times 0\times 1\times 3300\right)\right]}=795mg/kg$$

SQS_1^{nc} (non-carcinogenic SQS for soil ingestion-dermal absorption)	-	mg/kg
THQ (target hazard quotient)	1	unitless
BW (body weight)	70	kg
AT (averaging time)	25	year
EF (exposure frequency)	225	day/year
ED (exposure duration)	25	year
RfD_o (oral reference dose)	$7x10^{-4}$	mg/kg-day
IR (soil ingestion rate)	100	mg/day
RfD_{ABS} (dermally-adjusted reference dose)	$7x10^{-4}$	mg/kg-day
AF (skin-soil adherence factor)	0.2	mg/cm^2-event
ABS_d (dermal absorption factor)	-	unitless
EV (event frequency)	1	event/day
SA (skin surface area exposed)	3300	cm^2

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF CARBON TETRACHLORIDE

SQS_1^c calculated considering carcinogenic risks	24 mg/kg
SQS_1^{nc} calculated considering non-carcinogenic effects	795 mg/kg
SQS_1 for ingestion-dermal absorption pathway	**24 mg/kg**

SQS FOR INHALATION OF FUGITIVE PARTICULATES PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$PEF = Q/C_{wind} \times \frac{3600\ s/h}{0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)} \qquad (2.14)$$

$$PEF = 19.81 \times \frac{3600}{0.036 \times (1-0.2) \times (3.0/8.28)^3 \times (6.67 \times 10^{-2})} = 7.80 \times 10^8\ m^3/k$$

PEF (particulate emission factor)	-	m^3/kg
Q/C_{wind} (air dispersion factor for fugitive dusts)	19.81	$(g/m^2\text{-}s) / (kg/m^3)$
V (fraction of continuous vegetative cover)	0.2	unitless
U_m (mean annual wind speed)	3.0	m/s
U_t (equivalent threshold value of wind speed at 10 m)	8.28	m/s
F(x) (Function dependent on U_m/U_t derived using Cowherd et al.)	6.67×10^{-2}	unitless

$$SQS_2^c = \frac{TR \times AT \times 365\ d/yr}{URF \times EF \times ED \times \left[\frac{1}{PEF}\right]} \qquad (2.12)$$

$$SQS_2^c = \frac{10^{-6} \times 70 \times 365}{1.5 \times 10^{-2} \times 225 \times 25 \times \left[\frac{1}{7.80 \times 10^8}\right]} = 236{,}196\ mg/kg$$

SQS_2^c (carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	1.5×10^{-2}	$(mg/m^3)^{-1}$
EF (exposure frequency)	225	day/year
ED (exposure duration)	25	year
PEF (particulate emission factor)	7.80×10^8	m^3/kg

Calculation of SQS for Non-Carcinogenic Effects:

$$SQS_2^{nc} = \frac{THQ \times AT \times 365\ d/yr}{EF \times ED \times \left(\frac{1}{RfC} \times \frac{1}{PEF}\right)} \tag{2.13}$$

$$SQS_2^{c} = \frac{1 \times 25 \times 365}{225 \times 25 \times \left(\frac{1}{1.89 \times 10^{-1}} \times \frac{1}{7.80 \times 10^{8}}\right)} = 239{,}148{,}000\ mg/kg$$

$\boldsymbol{SQS_2^{nc}}$ (non-carcinogenic SQS for inhalation of fugitive particulates)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	25	year
EF (exposure frequency)	225	day/year
ED (exposure duration)	25	year
RfC (inhalation reference concentration)	1.89×10^{-1}	mg/m^3
PEF (particulate emission factor)	7.80×10^{8}	m^3/kg

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF CARBON TETRACHLORIDE

SQS_2^{c} calculated considering carcinogenic risks	236,196 mg/kg
SQS_2^{nc} calculated considering non-carcinogenic effects	239,148,000 mg/kg
SQS_2 for inhalation of fugitive particulates pathway	**236,196 mg/kg**

As can be seen above, SQS_2 calculated for inhalation of fugitive particulates pathway is quite higher than SQS_1 calculated for ingestion-dermal absorption pathway. Because of this reason, SQS_1 for ingestion-dermal absorption pathway is found to be sufficient for protection of human health. As a result, it is not necessary to calculate SQS_2^{c} and SQS_2^{nc} for organic compounds.

SQS FOR INHALATION OF VOLATILE CONTAMINANTS PATHWAY

Calculation of SQS for Carcinogenic Risks:

$$D_A=\frac{\left[\left(\theta_a^{10/3}D_iH^{'}+\theta_w^{10/3}D_w\right)/n^2\right]}{\rho_bK_d+\theta_w+\theta_aH^{'}} \tag{2.18}$$

$$D_A=\frac{\left[\left(0.28^{10/3}\right)\times\left(5.71\times10^{-2}\right)\times(1.13)+\left(0.15^{10/3}\right)\times\left(9.78\times10^{-6}\right)\right]/0.43^2}{(1.5)\times\left(4.39\times10^{1})\times(0.006\right)+(0.15)+(0.28)\times(1.13)}$$

$$D_A=5.82\times10^{-3}cm^2/s$$

$$VF=\frac{Q/C_{vol}\times(3.14\times D_A\times T)^{1/2}\times\left(10^{-4}\ m^2/cm^2\right)}{(2\times\rho_b\times D_A)} \tag{2.17}$$

$$VF=\frac{8.96\times\left[3.14\times\left(5.82\times10^{-3}\right)\times\left(9.5\times10^{8}\right)\right]^{1/2}\times10^{-4}}{2\times1.5\times\left(5.82\times10^{-3}\right)}=214\,m^3/kg$$

VF (soil to air volatilization factor)	-	m^3/kg
D_A (apparent diffusivity)	-	cm^2/s
Q/C_{vol} (air dispersion factor for volatiles)	8.96	$(g/m^2.s)/(kg/m^3)$
T (exposure interval)	9.5×10^8	s
ρ_b (dry soil bulk density)	1.5	g/cm^3
θ_a (air filled soil porosity)	0.28	cm^3/cm^3
n (total soil porosity)	0.43	cm^3/cm^3
θ_w (water filled soil porosity)	0.15	cm^3/cm^3
ρ_s (soil particle density)	2.65	g/cm^3
D_i (diffusivity in air)	5.71×10^{-2}	cm^2/s
$H^{'}$ (Henry's law constant)	1.13	unitless
D_w (diffusivity in water)	9.78×10^{-6}	cm^2/s
K_d (soil-water partition coefficient)	$K_d=K_{oc}\times f_{oc}$	cm^3/g
K_{oc} (soil organic carbon partition coefficient)	4.39×10^1	cm^3/g
f_{oc} (fraction of organic carbon in soil)	0.006	g/g

$$SQS_3^c = \frac{TR \times AT \times 365\ d/yr}{URF \times EF \times ED \times \left(\frac{1}{VF}\right)} \qquad (2.15)$$

$$SQS_3^c = \frac{10^{-6} \times 70 \times 365}{\left(1.5 \times 10^{-2}\right) \times 225 \times 25 \times \left(\frac{1}{214}\right)} \cong 0.06\ mg/kg$$

SQS_3^c (carcinogenic SQS for inhalation of volatile contaminants)	-	mg/kg
TR (target cancer risk)	10^{-6}	unitless
AT (averaging time)	70	year
URF (inhalation unit risk factor)	1.5×10^{-2}	$(mg/m^3)^{-1}$
EF (exposure frequency)	225	day/year
ED (exposure duration)	25	year
VF (soil to air volatilization factor)	1579	m^3/kg

Calculation of SQS for Non-Carcinogenic Effects:

$$SQS_3^{nc} = \frac{THQ \times AT \times 365\ d/yr}{EF \times ED \times \left(\frac{1}{RfC} \times \frac{1}{VF}\right)} \qquad (2.16)$$

$$SQS_3^{nc} = \frac{1 \times 25 \times 365}{225 \times 25 \times \left(\frac{1}{1.89 \times 10^{-1}} \times \frac{1}{214}\right)} = 66\ mg/kg$$

SQS_3^{nc} (non-carcinogenic SQS for inhalation of volatile contaminants)	-	mg/kg
THQ (target hazard quotient)	1	unitless
AT (averaging time)	25	year
EF (exposure frequency)	225	day/year
ED (exposure duration)	25	year
RfC (inhalation reference concentration)	1.89×10^{-1}	mg/m^3
VF (soil to air volatilization factor)	214	m^3/kg

Soil Saturation Concentration:

$$C_{sat}=\frac{S}{\rho_b}\left[K_d\rho_b+\theta_w+H^{'}\theta_a\right] \tag{2.19}$$

$$C_{sat}=\frac{7.93\times10^{2}}{1.5}\left[4.39\times10^{1}\times0.006\times1.5+0.15+1.13\times0.28\right]=455\ mg/kg$$

C_{sat} (soil saturation concentration)	-	mg/kg
S (solubility in water)	$7.93\text{x}10^2$	mg/L
ρ_b (dry soil bulk density)	1.5	kg/L
K_d (soil-water partition coefficient)	$K_d=K_{oc}\times f_{oc}$	L/kg
K_{oc} (soil organic carbon partition coefficient)	$4.39\text{x}10^1$	L/kg
f_{oc} (fraction of organic carbon in soil)	0.006 (%0.6)	g/g
θ_w (water filled soil porosity)	0.15	cm^3/cm^3
$H^{'}$ (Henry's law constant)	1.13	unitless
θ_a (air filled soil porosity)	0.28	cm^3/cm^3
n (total soil porosity)	0.43	cm^3/cm^3
ρ_s (soil particle density)	2.65	g/cm^3

COMPARISION OF SQSs CALCULATED FOR CARCINOGENIC AND NON-CARCINOGENIC EFFECTS OF CARBON TETRACHLORIDE

SQS_3^c calculated considering carcinogenic risks	0.06 mg/kg
SQS_3^{nc} calculated considering non-carcinogenic effects	66 mg/kg
Soil saturation concentration, C_{sat}	455 mg/kg
SQS_3 for inhalation of volatile contaminants pathway	**0.06 mg/kg**

SQS FOR MIGRATION TO GROUNDWATER PATHWAY

$$SQS_4 = C_w \left(K_d + \frac{\theta_w + \theta_a H^{'}}{\rho_b} \right) \tag{2.20}$$

$$SQS_4 = 4 \times 10^{-3} \left(4.39 \times 10^{1} \times 0.002 + \frac{0.3 + 0.13 \times 1.13}{1.5} \right) \cong 0.002 \text{ mg/kg}$$

***SQS*$_4$** (SQS for migration to groundwater pathway)	-	mg/kg
***C*$_w$** (target soil leachate concentration)	4x10^{-3} (WHO)*	mg/L
***K*$_d$** (soil-water partition coefficient)	$K_d = K_{oc} \times f_{oc}$	L/kg
***K*$_{oc}$** (soil organic carbon partition coefficient)	4.39x10^1	L/kg
***f*$_{oc}$** (fraction of organic carbon in soil)	0.002 (% 0.2)	g/g
θ_w (water filled soil porosity)	0.3	cm^3/cm^3
θ_a (air filled soil porosity)	0.13	cm^3/cm^3
$H^{'}$ (Henry’s law constant)	1.13	unitless
n (total soil porosity)	0.43	cm^3/cm^3
ρ_b (dry soil bulk density)	1.5	kg/L
ρ_s (soil particle density)	2.65	kg/L

* *DF* is taken as 1.

COMPARISION OF SQS WITH C_{sat}

SQS_4 calculated	0.002 mg/kg
Soil saturation concentration, C_{sat}	455 mg/kg
***SQS*$_4$ for migration to groundwater pathway**	**0.002 mg/kg**

SQSs CALCUATED FOR CARBON TETRACHLORIDE

1. Ingestion-dermal absorption pathway	24 mg/kg
2. Inhalation of fugitive particulates pathway	-
3. Inhalation of volatile contaminants pathway	0.06 mg/kg
4. Migration to groundwater pathway	0.002 mg/kg

APPENDIX-D

GENERIC SOIL QUALITY STANDARDS

The calculated generic SQSs are presented in the following tables:

- Table D.1 Generic SQSs for Residential Land Use
- Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker
- Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker

Table D.1 Generic SQSs for Residential Land Use

Compound [a]	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater** [l] **(mg/kg)**	
					$DF = 10$	$DF = 1$
ORGANICS						
Acenaphthene	000083-32-9	3,441 [b]	- [f]	-	225 [b,g]	22 [b,g]
Acetone	000067-64-1	70,393 [b,c]	114,431 [d]	-	67 [b,g]	7 [b,g]
Acrolein	000107-02-8	39 [b,c]	0.06 [b]	-	0.04 [b,g]	0.004 [b,g]
Acrylamide	000079-06-1	1 [e]	- [j]	-	0.0003 [e,g]	0.00003 [e,g]
Acrylonitrile	000107-13-1	1 [c,e]	0.1 [e]	-	0.0003 [e,g]	0.00003 [e,g]
Aldrin	000309-00-2	0.03 [e]	- [j]	-	0.006 [e,g]	0.0006 [e,g]
Anthracene	000120-12-7	17,203 [b]	- [f]	-	3,614 [b,g]	361 [b,g]
Atrazine	001912-24-9	2 [e]	- [j]	-	0.01 [h]	0.001 [h]
Benz[a]anthracene	000056-55-3	0.6 [e]	- [j]	-	0.3 [e,g]	0.03 [e,g]
Benzene	000071-43-2	12 [c,e]	0.5 [e]	-	0.005 [i]	0.0005 [i]
Benzidine	000092-87-5	0.002 [e]	- [j]	-	0.000008 [e,g]	0.0000008 [e,g]
Benzo[a]pyrene	000050-32-8	0.06 [e]	- [j]	-	0.1 [e,g]	0.01 [e,g]
Benzo[b]fluoranthene	000205-99-2	0.6 [e]	- [j]	-	1 [e,g]	0.1 [e,g]
Benzo[k]fluoranthene	000207-08-9	6 [e]	- [j]	-	11 [e,g]	1 [e,g]
Benzoic Acid	000065-85-0	244,420 [b]	- [j]	-	293 [b,g]	29 [b,g]
Bis(2-chloroethoxy)methane	000111-91-1	183 [b]	- [j]	-	0.3 [b,g]	0.03 [b,g]
Bis(2-chloroethyl)ether	000111-44-4	0.6 [c,e]	0.1 [e]	-	0.0002 [e,g]	0.00002 [e,g]
Bis(2-ethylhexyl)phthalate	000117-81-7	35 [e]	- [j]	-	19 [h]	2 [h]
Bis(chloromethyl)ether	000542-88-1	0.003 [c,e]	0.00003 [e]	-	0.0000007 [e,g]	0.00000007 [e,g]
Bromodichloromethane	000075-27-4	10 [c,e]	0.1 [e]	-	0.003 [e,g]	0.0003 [e,g]
Bromoform	000075-25-2	61 [e]	- [j]	-	0.3 [h]	0.03 [h]

Table D.1 Generic SQSs for Residential Land Use (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF = 10	**DF = 1**
Bromomethane	000074-83-9	110 [b,c]	3 [b]	-	0.1 [b,g]	0.01 [b,g]
Butanol, N-	000071-36-3	6,110 [b]	- [f]	-	8 [b,g]	0.8 [b,g]
Butyl Benzyl Phthlate	000085-68-7	256 [e]	- [j]	-	5 [e,g]	0.5 [e,g]
Carbaryl	000063-25-2	6,110 [b]	- [j]	-	33 [b,g]	3 [b,g]
Carbazole	000086-74-8	24 [e]	- [f]	-	0.6 [e,g]	0.06 [e,g]
Carbofuran	001563-66-2	306 [b]	- [j]	-	0.03 [h]	0.003 [h]
Carbon Disulfide	000075-15-0	7,821 [b,c]	372 [d]	-	11 [b,g]	1 [b,g]
Carbon Tetrachloride	000056-23-5	5 [c,e]	0.1 [e]	-	0.02 [h]	0.002 [h]
Chlordane	012789-03-6	2 [e]	- [j]	-	0.1 [h]	0.01 [h]
Chloroaniline, p-	000106-47-8	2 [e]	- [f]	-	0.001 [e,g]	0.0001 [e,g]
Chlorobenzene	000108-90-7	1,564 [b,c]	147 [b]	-	5 [b,g]	0.5 [b,g]
Chloroform	000067-66-3	21 [c,e]	0.1 [e]	-	0.8 [h]	0.08 [h]
Chloromethane	000074-87-3	- [f]	48 [b]	-	- [f]	- [f]
Chloronaphthalene, Beta-	000091-58-7	6,257 [b,c]	- [f]	-	151 [b,g]	15 [b,g]
Chlorophenol, 2-	000095-57-8	391 [b,c]	- [f]	-	1 [b,g]	0.1 [b,g]
Chrysene	000218-01-9	62 [e]	- [j]	-	33 [e,g]	3 [e,g]
Cresol, m-	000108-39-4	3,055 [b]	43,130 [d]	-	15 [b,g]	1 [b,g]
Cresol, o-	000095-48-7	3,055 [b]	87,730 [b]	-	15 [b,g]	1 [b,g]
Cresol, p-	000106-44-5	306 [b]	93,192 [b]	-	1 [b,g]	0.1 [b,g]
Cyclohexanone	000108-94-1	305,525 [b]	- [f]	-	429 [b,g]	43 [b,g]
DDD	000072-54-8	2 [e]	- [j]	-	2 [h]	0.2 [h]
DDE, p,p'-	000072-55-9	1 [e]	- [j]	-	2 [h]	0.2 [h]

Table D.1 Generic SQSs for Residential Land Use (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF = 10	**DF = 1**
DDT	000050-29-3	2 [e]	- [j]	-	3 [h]	0.3 [h]
Dibenz[a,h]anthracene	000053-70-3	0.06 [e]	- [j]	-	0.4 [e,g]	0.04 [e,g]
Dibromochloromethane	000124-48-1	6 [e]	0.3 [e]	-	0.3 [h]	0.03 [h]
Dibutyl Phthalate	000084-74-2	6,110 [b]	- [j]	-	79 [d]	9 [b,g]
Dichlorobenzene, 1,2-	000095-50-1	7,039 [b,c]	376 [d]	-	10 [h]	1 [h]
Dichlorobenzene, 1,4-	000106-46-7	118 [c,e]	1 [e]	-	3 [h]	0.3 [h]
Dichlorobenzidine, 3,3'-	000091-94-1	1 [e]	- [j]	-	0.01 [e,g]	0.001 [e,g]
Dichloroethane, 1,1-	000075-34-3	112 [c,e]	1 [e]	-	0.03 [e,g]	0.003 [e,g]
Dichloroethane, 1,2-	000107-06-2	7 [c,e]	0.2 [e]	-	0.002 [e,g]	0.0002 [e,g]
Dichloroethylene, 1,1-	000075-35-4	3,911 [b,c]	105 [b]	-	7 [b,g]	0.7 [b,g]
Dichloroethylene, 1,2-cis-	000156-59-2	156 [b,c]	- [f]	-	0.1 [h]	0.01 [h]
Dichloroethylene, 1,2-trans-	000156-60-5	1,564 [b,c]	68 [b]	-	2 [b,g]	0.2 [b,g]
Dichlorophenol, 2,4-	000120-83-2	183 [b]	- [f]	-	1 [b,g]	0.1 [b,g]
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	686 [b]	- [j]	-	0.08 [h]	0.008 [h]
Dichloropropane, 1,2-	000078-87-5	18 [c,e]	0.4 [e]	-	0.1 [h]	0.01 [h]
Dichloropropene, 1,3-	000542-75-6	6 [c,e]	0.9 [e]	-	0.002 [e,g]	0.0002 [e,g]
Dieldrin	000060-57-1	0.03 [e]	- [j]	-	0.002 [e,g]	0.0002 [e,g]
Diethyl Phthalate	000084-66-2	48,884 [b]	- [j]	-	120 [b,g]	12 [b,g]
Dimethylphenol, 2,4-	000105-67-9	1,222 [b]	- [f]	-	9 [b,g]	0.9 [b,g]
Dinitro-o-cresol, 4,6-	000534-52-1	6 [b]	- [f]	-	0.06 [b,g]	0.006 [b,g]
Dinitrophenol, 2,4-	000051-28-5	122 [b]	- [j]	-	0.1 [b,g]	0.01 [b,g]
Dinitrotoluene, 2,4-	000121-14-2	2 [e]	- [j]	-	0.003 [e,g]	0.0003 [e,g]

Table D.1 Generic SQSs for Residential Land Use (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF = 10	**DF = 1**
Dinitrotoluene, 2,6-	000606-20-2	61 [b]	- [f]	-	0.5 [b,g]	0.05 [b,g]
Diphenylhydrazine, 1,2-	000122-66-7	0.6 [e]	- [j]	-	0.003 [e,g]	0.0003 [e,g]
Endosulfan	000115-29-7	367 [b]	- [j]	-	30 [b,g]	3 [b,g]
Endrin	000072-20-8	18 [b]	- [j]	-	0.2 [h]	0.02 [h]
Ethylbenzene	000100-41-4	58 [c,e]	2 [e]	-	3 [h]	0.3 [h]
Fluoranthene	000206-44-0	2,294 [b]	- [j]	-	1,624 [b,g]	162 [b,g]
Fluorene	000086-73-7	2,294 [b]	- [f]	-	270 [b,g]	27 [b,g]
Furan	000110-00-9	78 [b,c]	- [f]	-	0.1 [b,g]	0.01 [b,g]
Heptachlor	000076-44-8	0.1 [e]	- [j]	-	0.01 [e,g]	0.001 [e,g]
Heptachlor Epoxide	001024-57-3	0.05 [e]	- [j]	-	0.002 [e,g]	0.0002 [e,g]
Hexachlorobenzene	000118-74-1	0.3 [e]	- [j]	-	0.005 [e,g]	0.0005 [e,g]
Hexachlorobutadiene	000087-68-3	6 [e]	- [j]	-	0.01 [h]	0.001 [h]
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	0.08 [e]	- [j]	-	0.0006 [e,g]	0.00006 [e,g]
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	0.3 [e]	- [j]	-	0.002 [e,g]	0.0002 [e,g]
Hexachlorocyclohexane, Gamma-(γ-HCH)	000058-89-9	0.5 [e]	- [j]	-	0.1 [h]	0.01 [h]
Hexachlorocyclopentadiene	000077-47-4	367 [b]	- [j]	-	7 [b,g]	0.7 [b,g]
Hexachloroethane	000067-72-1	35 [e]	- [j]	-	0.03 [e,g]	0.003 [e,g]
Indeno[1,2,3-cd]pyrene	000193-39-5	0.6 [e]	- [j]	-	4 [e,g]	0.4 [e,g]
Isophorone	000078-59-1	511 [e]	5,895 [d]	-	0.2 [e,g]	0.02 [e,g]
MCPA	000094-74-6	31 [b]	- [j]	-	0.005 [h]	0.0005 [h]
Maneb	012427-38-2	306 [b]	- [j]	-	3 [b,g]	0.3 [b,g]
Methoxychlor	000072-43-5	306 [b]	- [j]	-	11 [h]	1 [h]

Table D.1 Generic SQSs for Residential Land Use (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
Methyl tert-Butyl Ether (MTBE)	001634-04-4	355 [c,e]	20 [e]	-	0.08 [e,g]	0.008 [e,g]
Methylene Chloride	000075-09-2	85 [c,e]	5 [e]	-	0.05 [h]	0.005 [h]
Mirex	002385-85-5	0.03 [e]	- [j]	-	0.03 [e,g]	0.003 [e,g]
Naphthalene	000091-20-3	1,147 [b]	1 [e]	-	24 [b,g]	2 [b,g]
Nitrobenzene	000098-95-3	156 [b,c]	2 [e]	-	0.5 [b,g]	0.05 [b,g]
Nitroso-di-N-propylamine, N-	000621-64-7	0.07 [e]	0.1 [e]	-	0.00007 [e,g]	0.000007 [e,g]
Nitrosodimethylamine, N-	000062-75-9	0.01 [e]	0.006 [e]	-	0.2 [h]	0.02 [h]
Nitrosodiphenylamine, N-	000086-30-6	99 [e]	431 [e]	-	0.7 [e,g]	0.07 [e,g]
Pentachlorobenzene	000608-93-5	49 [b]	- [j]	-	2 [b,g]	0.2 [b,g]
Pentachlorophenol	000087-86-5	0.9 [e]	- [j]	-	0.02 [e,g]	0.002 [e,g]
Phenol	000108-95-2	18,331 [b]	32,674 [b]	-	63 [b,g]	6 [b,g]
Polychlorinated Biphenyls (high risk) [m]	001336-36-3	0.2 [e]	- [j]	-	0.05 [e,g]	0.005 [e,g]
Polychlorinated Biphenyls (low risk) [n]	001336-36-3	1 [e]	- [j]	-	0.3 [e,g]	0.03 [e,g]
Pyrene	000129-00-0	1,720 [b]	- [f]	-	1,191 [b,g]	119 [b,g]
Pyridine	000110-86-1	78 [b,c]	- [f]	-	0.1 [b,g]	0.01 [b,g]
Styrene	000100-42-5	15,643 [b,c]	867 [d]	-	0.2 [h]	0.02 [h]
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	18 [b]	- [j]	-	0.5 [b,g]	0.05 [b,g]
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	0.000004 [e]	- [j]	-	0.000003 [e,g]	0.0000003 [e,g]
Tetrachloroethane, 1,1,1,2-	000630-20-6	25 [c,e]	0.8 [e]	-	0.01 [e,g]	0.001 [e,g]
Tetrachloroethylene	000127-18-4	1 [c,e]	0.4 [e]	-	0.2 [h]	0.02 [h]
Toluene	000108-88-3	6,257 [b,c]	818 [d]	-	5 [h]	0.5 [h]
Total Petroleum Hydrocarbons (Aliphatic) (EC>16 - EC35) [o]	000000-00-9	156,429 [b,c]	- [j]	-	146 [b,g]	15 [b,g]

Table D.1 Generic SQSs for Residential Land Use (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF = 10	**DF = 1**
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8) [o]	000000-01-0	4,693 [b,c]	- [j]	-	4 [b,g]	0.4 [b,g]
Total Petroleum Hydrocarbons (Aliphatic) (EC>8 - EC16) [o]	000000-01-1	7,821 [b,c]	- [j]	-	7 [b,g]	0.7 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC>16 - EC35) [o]	000000-01-2	2,346 [b,c]	- [j]	-	2 [b,g]	0.2 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9) [o]	000000-01-3	15,643 [b,c]	- [j]	-	15 [b,g]	1 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC>9 - EC16) [o]	000000-01-4	1,564 [b,c]	- [j]	-	1 [b,g]	0.1 [b,g]
Toxaphene	008001-35-2	0.4 [e]	- [j]	-	0.09 [e,g]	0.009 [e,g]
Tributyltin Oxide	000056-35-9	18 [b]	- [j]	-	5,672 [b,g]	567 [b,g]
Trichlorobenzene, 1,2,4-	000120-82-1	22 [c,e]	27 [b]	-	0.07 [e,g]	0.007 [e,g]
Trichloroethane, 1,1,1-	000071-55-6	156,429 [b,c]	640 [d]	-	256 [b,g]	26 [b,g]
Trichloroethane, 1,1,2-	000079-00-5	11 [c,e]	0.5 [e]	-	0.004 [e,g]	0.0004 [e,g]
Trichloroethylene	000079-01-6	108 [c,e]	1 [e]	-	0.07 [h]	0.007 [h]
Trichlorophenol, 2,4,5-	000095-95-4	6,110 [b]	- [f]	-	29 [b,g]	3 [b,g]
Trichlorophenol, 2,4,6-	000088-06-2	44 [e]	78 [e]	-	0.03 [e,g]	0.003 [e,g]
Vinyl Acetate	000108-05-4	78,214 [b,c]	400 [b]	-	78 [b,g]	8 [b,g]
Vinyl Chloride	000075-01-4	0.9 [c,e]	0.2 [e]	-	0.0003 [e,g]	0.00003 [e,g]
Xylene, Mixture	001330-20-7	15,643 [b,c]	258 [d]	-	5 [h]	0.5 [h]
Xylene, m-	000108-38-3	- [f]	387 [d]	-	5 [h]	0.5 [h]
Xylene, o-	000095-47-6	- [f]	434 [d]	-	5 [h]	0.5 [h]
Xylene, p-	000106-42-3	- [f]	389 [d]	-	5 [h]	0.5 [h]

Table D.1 Generic SQSs for Residential Land Use (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
INORGANICS						
Arsenic, Inorganic	007440-38-2	0.4 [e]	-	1,321 [e]	3 [i]	0.3 [i]
Barium	007440-39-3	15,643 [b,c]	-	- [k]	281 [h]	28 [h]
Beryllium and compounds	007440-41-7	156 [b,c]	-	2,367 [e]	402 [b,g]	40 [b,g]
Cadmium (Diet)	007440-43-9	70 [b]	-	3,155 [e]	3 [i]	0.3 [i]
Chromium (III) (Insoluble Salts)	016065-83-1	117,321 [b,c]	-	- [f]	750,000 [i]	75,000 [i]
Chromium VI (particulates)	018540-29-9	1 [c,e]	-	68 [e]	7 [i]	0.7 [i]
Chromium, Total (1:6 ratio Cr VI : Cr III)	007440-47-3	- [f]	-	473 [e]	750,000 [i]	75,000 [i]
Cobalt	007440-48-4	23 [b,c]	-	631 [e]	5 [b,g]	0.5 [b,g]
Copper	007440-50-8	3,129 [b,c]	-	- [f]	704 [i]	70 [i]
Cyanide (CN-)	000057-12-5	1,564 [b,c]	-	- [f]	5 [i]	0.5 [i]
Lead and Compounds	007439-92-1	400 [p]	-	- [f]	90 [i]	9 [i]
Mercury (elemental)	007439-97-6	13 [b,c]	2 [b]	-	0.4 [i]	0.04 [i]
Molybdenum	007439-98-7	391 [b,c]	-	- [f]	14 [h]	1 [h]
Nickel Soluble Salts	007440-02-0	1,564 [b,c]	-	21,845 [e]	12 [i]	1 [i]
Selenium	007782-49-2	391 [b,c]	-	- [k]	0.2 [i]	0.02 [i]
Silver	007440-22-4	391 [b,c]	-	- [f]	12 [b,g]	1 [b,g]
Tetraethyl Lead	000078-00-2	0.006 [b]	-	- [f]	0.0001 [b,g]	0.00001 [b,g]
Thallium (Soluble Salts)	007440-28-0	0.8 [b,c]	-	- [f]	0.3 [b,g]	0.03 [b,g]
Thiocyanate	000463-56-9	16 [b,c]	-	- [f]	0.02 [b,g]	0.002 [b,g]
Tin	007440-31-5	46,929 [b,c]	-	- [f]	54,794 [b,g]	5,479 [b,g]
Titanium Tetrachloride	007550-45-0	- [f]	-	243,417 [b]	- [f]	- [f]

Table D.1 Generic SQSs for Residential Land Use (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater[l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
Vanadium, Metallic	007440-62-2	5[b,c]	-	-[f]	26[b,g]	3[b,g]
Zinc (Metallic)	007440-66-6	23,464[b,c]	-	-[f]	6,373[b,g]	637[b,g]

a) SQSs are calculated based on human health criteria only.
b) Calculated values correspond to a noncancer hazard quotient of 1.
c) No dermal absorption data available; calculated based on ingestion data only.
d) Soil saturation concentration (C_{sat}).
e) Calculated values correspond to a cancer risk of 1/1.000.000.
f) No toxicity criteria available.
g) SQS is based on HBL (Health Based Limit).
h) SQS is based on WHO Drinking Water Standards (WHO, 2008).
i) SQS is based on TS-266 Standards (TSE, 2005).
j) SQS cannot be calculated since D_i and D_w values are not available for this compound.
k) Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration.
l) If depth to aquifer is less than 3m, or aquifer is fractured or carstic, or source area is greater than or equal to 10ha, then DF is taken as 1; in other conditions DF is taken as 10.
m) For PCB mixtures other than Aroclor 1016.
n) Only for mixtures of Aroclor 1016.
o) EC: Equivalent carbon number.
p) SQS is adopted from US EPA, 1994.

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker

Compound [a]	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater** [l] **(mg/kg)**	
					$DF = 10$	**$DF = 1$**
ORGANICS						
Acenaphthene	000083-32-9	36,670 [b]	- [f]	-	350 [b,g]	35 [b,g]
Acetone	000067-64-1	- [k]	96,897 [d]	-	105 [b,g]	10 [b,g]
Acrolein	000107-02-8	568 [b,c]	0.03 [b]	-	0.06 [b,g]	0.006 [b,g]
Acrylamide	000079-06-1	4 [e]	- [j]	-	0.0007 [e,g]	0.00007 [e,g]
Acrylonitrile	000107-13-1	6 [c,e]	0.07 [e]	-	0.0006 [e,g]	0.00006 [e,g]
Aldrin	000309-00-2	0.1 [e]	- [j]	-	0.02 [e,g]	0.002 [e,g]
Anthracene	000120-12-7	183,351 [b]	- [f]	-	5,621 [b,g]	562 [b,g]
Atrazine	001912-24-9	8 [e]	- [j]	-	0.01 [h]	0.001 [h]
Benz[a]anthracene	000056-55-3	2 [e]	- [j]	-	0.8 [e,g]	0.08 [e,g]
Benzene	000071-43-2	58 [c,e]	0.3 [e]	-	0.005 [i]	0.0005 [i]
Benzidine	000092-87-5	0.008 [e]	- [j]	-	0.00002 [e,g]	0.000002 [e,g]
Benzo[a]pyrene	000050-32-8	0.2 [e]	- [j]	-	0.3 [e,g]	0.03 [e,g]
Benzo[b]fluoranthene	000205-99-2	2 [e]	- [j]	-	3 [e,g]	0.3 [e,g]
Benzo[k]fluoranthene	000207-08-9	23 [e]	- [j]	-	26 [e,g]	3 [e,g]
Benzoic Acid	000065-85-0	- [k]	- [j]	-	457 [b,g]	46 [b,g]
Bis(2-chloroethoxy)methane	000111-91-1	2,052 [b]	- [j]	-	0.4 [b,g]	0.04 [b,g]
Bis(2-chloroethyl)ether	000111-44-4	3 [c,e]	0.08 [e]	-	0.0004 [e,g]	0.00004 [e,g]
Bis(2-ethylhexyl)phthalate	000117-81-7	137 [e]	- [j]	-	19 [h]	2 [h]
Bis(chloromethyl)ether	000542-88-1	0.01 [c,e]	0.00002 [e]	-	0.000002 [e,g]	0.0000002 [e,g]
Bromodichloromethane	000075-27-4	51 [c,e]	0.07 [e]	-	0.007 [e,g]	0.0007 [e,g]
Bromoform	000075-25-2	242 [e]	- [j]	-	0.3 [h]	0.03 [h]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
Bromomethane	000074-83-9	1,590 [b,c]	2 [b]	-	0.2 [b,g]	0.02 [b,g]
Butanol, N-	000071-36-3	68,407 [b]	- [f]	-	12 [b,g]	1 [b,g]
Butyl Benzyl Phthlate	000085-68-7	1,008 [e]	- [j]	-	12 [e,g]	1 [e,g]
Carbaryl	000063-25-2	68,407 [b]	- [j]	-	52 [b,g]	5 [b,g]
Carbazole	000086-74-8	96 [e]	- [f]	-	1 [e,g]	0.1 [e,g]
Carbofuran	001563-66-2	3,420 [b]	- [j]	-	0.03 [h]	0.003 [h]
Carbon Disulfide	000075-15-0	113,556 [b,c]	188 [d]	-	17 [b,g]	2 [b,g]
Carbon Tetrachloride	000056-23-5	24 [c,e]	0.06 [e]	-	0.02 [h]	0.002 [h]
Chlordane	012789-03-6	7 [e]	- [j]	-	0.1 [h]	0.01 [h]
Chloroaniline, p-	000106-47-8	10 [e]	- [f]	-	0.003 [e,g]	0.0003 [e,g]
Chlorobenzene	000108-90-7	22,711 [b,c]	74 [b]	-	8 [b,g]	0.8 [b,g]
Chloroform	000067-66-3	103 [c,e]	0.07 [e]	-	0.8 [h]	0.08 [h]
Chloromethane	000074-87-3	- [f]	24 [b]	-	- [f]	- [f]
Chloronaphthalene, Beta-	000091-58-7	90,844 [b,c]	- [f]	-	234 [b,g]	23 [b,g]
Chlorophenol, 2-	000095-57-8	5,678 [b,c]	- [f]	-	2 [b,g]	0.2 [b,g]
Chrysene	000218-01-9	234 [e]	- [j]	-	79 [e,g]	8 [e,g]
Cresol, m-	000108-39-4	34,203 [b]	43,130 [d]	-	23 [b,g]	2 [b,g]
Cresol, o-	000095-48-7	34,203 [b]	44,287 [b]	-	23 [b,g]	2 [b,g]
Cresol, p-	000106-44-5	3,420 [b]	47,044 [b]	-	2 [b,g]	0.2 [b,g]
Cyclohexanone	000108-94-1	- [k]	- [f]	-	667 [b,g]	67 [b,g]
DDD	000072-54-8	8 [e]	- [j]	-	2 [h]	0.2 [h]
DDE, p,p'-	000072-55-9	6 [e]	- [j]	-	2 [h]	0.2 [h]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
DDT	000050-29-3	8 [e]	- [j]	-	3 [h]	0.3 [h]
Dibenz[a,h]anthracene	000053-70-3	0.2 [e]	- [j]	-	0.8 [e,g]	0.08 [e,g]
Dibromochloromethane	000124-48-1	23 [e]	1 [e]	-	0.3 [h]	0.03 [h]
Dibutyl Phthalate	000084-74-2	68,407 [b]	- [j]	-	79 [d]	14 [b,g]
Dichlorobenzene, 1,2-	000095-50-1	102,200 [b,c]	376 [d]	-	10 [h]	1 [h]
Dichlorobenzene, 1,4-	000106-46-7	589 [c,e]	0.6 [e]	-	3 [h]	0.3 [h]
Dichlorobenzidine, 3,3'-	000091-94-1	4 [e]	- [j]	-	0.02 [e,g]	0.002 [e,g]
Dichloroethane, 1,1-	000075-34-3	558 [c,e]	0.8 [e]	-	0.08 [e,g]	0.008 [e,g]
Dichloroethane, 1,2-	000107-06-2	35 [c,e]	0.1 [e]	-	0.005 [e,g]	0.0005 [e,g]
Dichloroethylene, 1,1-	000075-35-4	56,778 [b,c]	53 [b]	-	10 [b,g]	1 [b,g]
Dichloroethylene, 1,2-cis-	000156-59-2	2,271 [b,c]	- [f]	-	0.1 [h]	0.01 [h]
Dichloroethylene, 1,2-trans-	000156-60-5	22,711 [b,c]	35 [b]	-	3 [b,g]	0.3 [b,g]
Dichlorophenol, 2,4-	000120-83-2	2,052 [b]	- [f]	-	0.6 [b,g]	0.06 [b,g]
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	8,538 [b]	- [j]	-	0.08 [h]	0.008 [h]
Dichloropropane, 1,2-	000078-87-5	88 [c,e]	0.2 [e]	-	0.1 [h]	0.01 [h]
Dichloropropene, 1,3-	000542-75-6	32 [c,e]	0.6 [e]	-	0.006 [e,g]	0.0006 [e,g]
Dieldrin	000060-57-1	0.1 [e]	- [j]	-	0.004 [e,g]	0.0004 [e,g]
Diethyl Phthalate	000084-66-2	547,256 [b]	- [j]	-	186 [b,g]	19 [b,g]
Dimethylphenol, 2,4-	000105-67-9	13,681 [b]	- [f]	-	13 [b,g]	1 [b,g]
Dinitro-o-cresol, 4,6-	000534-52-1	68 [b]	- [f]	-	0.1 [b,g]	0.01 [b,g]
Dinitrophenol, 2,4-	000051-28-5	1,368 [b]	- [j]	-	0.2 [b,g]	0.02 [b,g]
Dinitrotoluene, 2,4-	000121-14-2	6 [e]	- [j]	-	0.007 [e,g]	0.0007 [e,g]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF = 10	**DF = 1**
Dinitrotoluene, 2,6-	000606-20-2	687 [b]	- [f]	-	0.8 [b,g]	0.08 [b,g]
Diphenylhydrazine, 1,2-	000122-66-7	2 [e]	- [j]	-	0.006 [e,g]	0.0006 [e,g]
Endosulfan	000115-29-7	4,104 [b]	- [j]	-	47 [b,g]	5 [b,g]
Endrin	000072-20-8	205 [b]	- [j]	-	0.2 [h]	0.02 [h]
Ethylbenzene	000100-41-4	289 [c,e]	11 [e]	-	3 [h]	0.3 [h]
Fluoranthene	000206-44-0	24,447 [b]	- [j]	-	2,525 [b,g]	253 [b,g]
Fluorene	000086-73-7	24,447 [b]	- [f]	-	421 [b,g]	42 [b,g]
Furan	000110-00-9	1,136 [b,c]	- [f]	-	0.2 [b,g]	0.02 [b,g]
Heptachlor	000076-44-8	0.4 [e]	- [j]	-	0.03 [e,g]	0.003 [e,g]
Heptachlor Epoxide	001024-57-3	0.2 [e]	- [j]	-	0.004 [e,g]	0.0004 [e,g]
Hexachlorobenzene	000118-74-1	1 [e]	- [j]	-	0.01 [e,g]	0.001 [e,g]
Hexachlorobutadiene	000087-68-3	25 [e]	- [j]	-	0.01 [h]	0.001 [h]
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	0.3 [e]	- [j]	-	0.001 [e,g]	0.0001 [e,g]
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	1 [e]	- [j]	-	0.005 [e,g]	0.0005 [e,g]
Hexachlorocyclohexane, Gamma- (γ-HCH)	000058-89-9	2 [e]	- [j]	-	0.1 [h]	0.01 [h]
Hexachlorocyclopentadiene	000077-47-4	4,104 [b]	- [j]	-	11 [b,g]	1 [b,g]
Hexachloroethane	000067-72-1	137 [e]	- [j]	-	0.07 [e,g]	0.007 [e,g]
Indeno[1,2,3-cd]pyrene	000193-39-5	2 [e]	- [j]	-	8 [e,g]	0.8 [e,g]
Isophorone	000078-59-1	2,016 [e]	5,895 [d]	-	0.6 [e,g]	0.06 [e,g]
MCPA	000094-74-6	342 [b]	- [j]	-	0.005 [h]	0.0005 [h]
Maneb	012427-38-2	3,420 [b]	- [j]	-	4 [b,g]	0.4 [b,g]
Methoxychlor	000072-43-5	3,420 [b]	- [j]	-	11 [h]	1 [h]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF **= 10**	DF **= 1**
Methyl tert-Butyl Ether (MTBE)	001634-04-4	1,766 [c,e]	12 [e]	-	0.2 [e,g]	0.02 [e,g]
Methylene Chloride	000075-09-2	424 [c,e]	3 [e]	-	0.05 [h]	0.005 [h]
Mirex	002385-85-5	0.1 [e]	- [j]	-	0.06 [e,g]	0.006 [e,g]
Naphthalene	000091-20-3	12,223 [b]	0.9 [e]	-	37 [b,g]	4 [b,g]
Nitrobenzene	000098-95-3	2,271 [b,c]	1 [e]	-	0.7 [b,g]	0.07 [b,g]
Nitroso-di-N-propylamine, N-	000621-64-7	0.3 [e]	0.06 [e]	-	0.0002 [e,g]	0.00002 [e,g]
Nitrosodimethylamine, N-	000062-75-9	0.04 [e]	0.004 [e]	-	0.2 [h]	0.02 [h]
Nitrosodiphenylamine, N-	000086-30-6	391 [e]	261 [e]	-	2 [e,g]	0.2 [e,g]
Pentachlorobenzene	000608-93-5	547 [b]	- [j]	-	3 [b,g]	0.3 [b,g]
Pentachlorophenol	000087-86-5	3 [e]	- [j]	-	0.004 [e,g]	0.0004 [e,g]
Phenol	000108-95-2	205,221 [b]	16,494 [b]	-	98 [b,g]	10 [b,g]
Polychlorinated Biphenyls (high risk) [m]	001336-36-3	0.8 [e]	- [j]	-	0.1 [e,g]	0.01 [e,g]
Polychlorinated Biphenyls (low risk) [n]	001336-36-3	4 [e]	- [j]	-	0.6 [e,g]	0.06 [e,g]
Pyrene	000129-00-0	18,335 [b]	- [f]	-	1,853 [b,g]	185 [b,g]
Pyridine	000110-86-1	1,136 [b,c]	- [f]	-	0.2 [b,g]	0.02 [b,g]
Styrene	000100-42-5	227,111 [b,c]	867 [d]	-	0.2 [h]	0.02 [h]
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	205 [b]	- [j]	-	0.8 [b,g]	0.08 [b,g]
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	0.00002 [e]	- [j]	-	0.000006 [e,g]	0.0000006 [e,g]
Tetrachloroethane, 1,1,1,2-	000630-20-6	122 [c,e]	0.5 [e]	-	0.02 [e,g]	0.002 [e,g]
Tetrachloroethylene	000127-18-4	6 [c,e]	0.3 [e]	-	0.2 [h]	0.02 [h]
Toluene	000108-88-3	90,844 [b,c]	818 [d]	-	5 [h]	0.5 [h]
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35) [o]	000000-00-9	- [k]	- [j]	-	227 [b,g]	23 [b,g]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8) [o]	000000-01-0	68,133 [b,c]	- [j]	-	7 [b,g]	0.7 [b,g]
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16) [o]	000000-01-1	113,556 [b,c]	- [j]	-	11 [b,g]	1 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35) [o]	000000-01-2	34,067 [b,c]	- [j]	-	3 [b,g]	0.3 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9) [o]	000000-01-3	227,111 [b,c]	- [j]	-	23 [b,g]	2 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16) [o]	000000-01-4	22,711 [b,c]	- [j]	-	2 [b,g]	0.2 [b,g]
Toxaphene	008001-35-2	2 [e]	- [j]	-	0.2 [e,g]	0.02 [e,g]
Tributyltin Oxide	000056-35-9	205 [b]	- [j]	-	8,823 [b,g]	882 [b,g]
Trichlorobenzene, 1,2,4-	000120-82-1	110 [c,e]	14 [b]	-	0.2 [e,g]	0.02 [e,g]
Trichloroethane, 1,1,1-	000071-55-6	- [k]	640 [d]	-	398 [b,g]	40 [b,g]
Trichloroethane, 1,1,2-	000079-00-5	56 [c,e]	0.3 [e]	-	0.009 [e,g]	0.0009 [e,g]
Trichloroethylene	000079-01-6	539 [c,e]	0.7 [e]	-	0.07 [h]	0.007 [h]
Trichlorophenol, 2,4,5-	000095-95-4	68,407 [b]	- [f]	-	45 [b,g]	5 [b,g]
Trichlorophenol, 2,4,6-	000088-06-2	174 [e]	47 [e]	-	0.07 [e,g]	0.007 [e,g]
Vinyl Acetate	000108-05-4	- [k]	202 [b]	-	121 [b,g]	12 [b,g]
Vinyl Chloride	000075-01-4	4 [c,e]	0.1 [e]	-	0.0008 [e,g]	0.00008 [e,g]
Xylene, Mixture	001330-20-7	227,111 [b,c]	134 [d]	-	5 [h]	0.5 [h]
Xylene, m-	000108-38-3	- [f]	387 [d]	-	5 [h]	0.5 [h]
Xylene, o-	000095-47-6	- [f]	434 [d]	-	5 [h]	0.5 [h]
Xylene, p-	000106-42-3	- [f]	389 [d]	-	5 [h]	0.5 [h]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater[l] (mg/kg)**	
					DF = 10	**DF = 1**
INORGANICS						
Arsenic, Inorganic	007440-38-2	2 [e]	-	825 [e]	3 [i]	0.3 [i]
Barium	007440-39-3	227,111 [b,c]	-	633,106 [b]	281 [h]	28 [h]
Beryllium and compounds	007440-41-7	2,271 [b,c]	-	1,477 [e]	625 [b,g]	62 [b,g]
Cadmium (Diet)	007440-43-9	898 [b]	-	1,970 [e]	3 [i]	0.3 [i]
Chromium (III) (Insoluble Salts)	016065-83-1	- [k]	-	- [f]	750,000 [i]	75,000 [i]
Chromium VI (particulates)	018540-29-9	6 [c,e]	-	42 [e]	7 [i]	0.7 [i]
Chromium, Total (1:6 ratio Cr VI : Cr III)	007440-47-3	- [f]	-	295 [e]	750,000 [i]	75,000 [i]
Cobalt	007440-48-4	341 [b,c]	-	394 [e]	8 [b,g]	0.8 [b,g]
Copper	007440-50-8	45,422 [b,c]	-	- [f]	704 [i]	70 [i]
Cyanide (CN-)	000057-12-5	22,711 [b,c]	-	- [f]	5 [i]	0.5 [i]
Lead and Compounds	007439-92-1	400 [o]	-	- [f]	90 [i]	9 [i]
Mercury (elemental)	007439-97-6	182 [b,c]	0.5 [b]	-	0.4 [i]	0.04 [i]
Molybdenum	007439-98-7	5,678 [b,c]	-	- [f]	14 [h]	1 [h]
Nickel Soluble Salts	007440-02-0	22,711 [b,c]	-	13,636 [e]	12 [i]	1 [i]
Selenium	007782-49-2	5,678 [b,c]	-	- [k]	0.2 [i]	0.02 [i]
Silver	007440-22-4	5,678 [b,c]	-	- [f]	19 [b,g]	2 [b,g]
Tetraethyl Lead	000078-00-2	0.07 [b]	-	- [f]	0.0002 [b,g]	0.00002 [b,g]
Thallium (Soluble Salts)	007440-28-0	11 [b,c]	-	- [f]	0.4 [b,g]	0.04 [b,g]
Thiocyanate	000463-56-9	227 [b,c]	-	- [f]	0.02 [b,g]	0.002 [b,g]
Tin	007440-31-5	681,333 [b,c]	-	- [f]	85,235 [b,g]	8,523 [b,g]
Titanium Tetrachloride	007550-45-0	- [f]	-	126,621 [b]	- [f]	- [f]

Table D.2 Generic SQSs for Commercial/Industrial Land Use: Outdoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
Vanadium, Metallic	007440-62-2	79 [b,c]	-	- [f]	40 [b,g]	4 [b,g]
Zinc (Metallic)	007440-66-6	340,667 [b,c]	-	- [f]	9,913 [b,g]	991 [b,g]

a) SQSs are calculated based on human health criteria only.
b) Calculated values correspond to a noncancer hazard quotient of 1.
c) No dermal absorption data available; calculated based on ingestion data only.
d) Soil saturation concentration (C_{sat}).
e) Calculated values correspond to a cancer risk of 1/1.000.000.
f) No toxicity criteria available.
g) SQS is based on HBL (Health Based Limit).
h) SQS is based on WHO Drinking Water Standards (WHO, 2008).
i) SQS is based on TS-266 Standards (TSE, 2005).
j) SQS cannot be calculated since D_i and D_w values are not available for this compound.
k) Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration.
l) If depth to aquifer is less than 3m, or aquifer is fractured or carstic, or source area is greater than or equal to 10ha, then DF is taken as 1; in other conditions DF is taken as 10.
m) For PCB mixtures other than Aroclor 1016.
n) Only for mixtures of Aroclor 1016.
o) EC: Equivalent carbon number.
p) SQS is adopted from US EPA, 1994.

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker

Compound [a]	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater** [l] **(mg/kg)**	
					$DF = 10$	$DF = 1$
ORGANICS						
Acenaphthene	000083-32-9	122,640 [b]	-	-	315 [b,g]	31 [b,g]
Acetone	000067-64-1	- [k]	-	-	94 [b,g]	9 [b,g]
Acrolein	000107-02-8	1,022 [b,c]	-	-	0.05 [b,g]	0.005 [b,g]
Acrylamide	000079-06-1	4 [e]	-	-	0.0006 [e,g]	0.00006 [e,g]
Acrylonitrile	000107-13-1	4 [c,e]	-	-	0.0006 [e,g]	0.00006 [e,g]
Aldrin	000309-00-2	0.1 [e]	-	-	0.01 [e,g]	0.001 [e,g]
Anthracene	000120-12-7	613,200 [b]	-	-	5,059 [b,g]	506 [b,g]
Atrazine	001912-24-9	9 [e]	-	-	0.01 [h]	0.001 [h]
Benz[a]anthracene	000056-55-3	3 [e]	-	-	0.7 [e,g]	0.07 [e,g]
Benzene	000071-43-2	37 [c,e]	-	-	0.005 [i]	0.0005 [i]
Benzidine	000092-87-5	0.009 [e]	-	-	0.00002 [e,g]	0.000002 [e,g]
Benzo[a]pyrene	000050-32-8	0.3 [e]	-	-	0.2 [e,g]	0.02 [e,g]
Benzo[b]fluoranthene	000205-99-2	3 [e]	-	-	2 [e,g]	0.2 [e,g]
Benzo[k]fluoranthene	000207-08-9	28 [e]	-	-	23 [e,g]	2 [e,g]
Benzoic Acid	000065-85-0	- [k]	-	-	411 [b,g]	41 [b,g]
Bis(2-chloroethoxy)methane	000111-91-1	6,132 [b]	-	-	0.4 [b,g]	0.04 [b,g]
Bis(2-chloroethyl)ether	000111-44-4	2 [c,e]	-	-	0.0003 [e,g]	0.00003 [e,g]
Bis(2-ethylhexyl)phthalate	000117-81-7	146 [e]	-	-	19 [h]	2 [h]
Bis(chloromethyl)ether	000542-88-1	0.009 [c,e]	-	-	0.000002 [e,g]	0.0000002 [e,g]
Bromodichloromethane	000075-27-4	33 [c,e]	-	-	0.006 [e,g]	0.0006 [e,g]
Bromoform	000075-25-2	259 [e]	-	-	0.3 [h]	0.03 [h]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
Bromomethane	000074-83-9	2,862 [b,c]	-	-	0.2 [b,g]	0.02 [b,g]
Butanol, N-	000071-36-3	204,400 [b]	-	-	11 [b,g]	1 [b,g]
Butyl Benzyl Phthlate	000085-68-7	1,076 [e]	-	-	11 [e,g]	1 [e,g]
Carbaryl	000063-25-2	204,400 [b]	-	-	47 [b,g]	5 [b,g]
Carbazole	000086-74-8	102 [e]	-	-	1 [e,g]	0.1 [e,g]
Carbofuran	001563-66-2	10,220 [b]	-	-	0.03 [h]	0.003 [h]
Carbon Disulfide	000075-15-0	204,400 [b,c]	-	-	15 [b,g]	2 [b,g]
Carbon Tetrachloride	000056-23-5	16 [c,e]	-	-	0.02 [h]	0.002 [h]
Chlordane	012789-03-6	6 [e]	-	-	0.1 [h]	0.01 [h]
Chloroaniline, p-	000106-47-8	10 [e]	-	-	0.003 [e,g]	0.0003 [e,g]
Chlorobenzene	000108-90-7	40,880 [b,c]	-	-	7 [b,g]	0.7 [b,g]
Chloroform	000067-66-3	66 [c,e]	-	-	0.8 [h]	0.08 [h]
Chloromethane	000074-87-3	- [f]	-	-	- [f]	- [f]
Chloronaphthalene, Beta-	000091-58-7	163,520 [b,c]	-	-	211 [b,g]	21 [b,g]
Chlorophenol, 2-	000095-57-8	10,220 [b,c]	-	-	2 [b,g]	0.2 [b,g]
Chrysene	000218-01-9	280 [e]	-	-	71 [e,g]	7 [e,g]
Cresol, m-	000108-39-4	102,200 [b]	-	-	20 [b,g]	2 [b,g]
Cresol, o-	000095-48-7	102,200 [b]	-	-	21 [b,g]	2 [b,g]
Cresol, p-	000106-44-5	10,220 [b]	-	-	2 [b,g]	0.2 [b,g]
Cyclohexanone	000108-94-1	- [k]	-	-	600 [b,g]	60 [b,g]
DDD	000072-54-8	9 [e]	-	-	2 [h]	0.2 [h]
DDE, p,p'-	000072-55-9	6 [e]	-	-	2 [h]	0.2 [h]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	**$DF = 1$**
DDT	000050-29-3	6 [e]	-	-	3 [h]	0.3 [h]
Dibenz[a,h]anthracene	000053-70-3	0.3 [e]	-	-	0.7 [e,g]	0.07 [e,g]
Dibromochloromethane	000124-48-1	24 [e]	-	-	0.3 [h]	0.03 [h]
Dibutyl Phthalate	000084-74-2	204,400 [b]	-	-	129 [b,g]	13 [b,g]
Dichlorobenzene, 1,2-	000095-50-1	183,960 [b,c]	-	-	10 [h]	1 [h]
Dichlorobenzene, 1,4-	000106-46-7	379 [c,e]	-	-	3 [h]	0.3 [h]
Dichlorobenzidine, 3,3'-	000091-94-1	5 [e]	-	-	0.02 [e,g]	0.002 [e,g]
Dichloroethane, 1,1-	000075-34-3	359 [c,e]	-	-	0.07 [e,g]	0.007 [e,g]
Dichloroethane, 1,2-	000107-06-2	22 [c,e]	-	-	0.004 [e,g]	0.0004 [e,g]
Dichloroethylene, 1,1-	000075-35-4	102,200 [b,c]	-	-	9 [b,g]	0.9 [b,g]
Dichloroethylene, 1,2-cis-	000156-59-2	4,088 [b,c]	-	-	0.1 [h]	0.01 [h]
Dichloroethylene, 1,2-trans-	000156-60-5	40,880 [b,c]	-	-	3 [b,g]	0.3 [b,g]
Dichlorophenol, 2,4-	000120-83-2	6,132 [b]	-	-	0.5 [b,g]	0.05 [b,g]
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	20,440 [b]	-	-	0.08 [h]	0.008 [h]
Dichloropropane, 1,2-	000078-87-5	57 [c,e]	-	-	0.1 [h]	0.01 [h]
Dichloropropene, 1,3-	000542-75-6	20 [c,e]	-	-	0.005 [e,g]	0.0005 [e,g]
Dieldrin	000060-57-1	0.1 [e]	-	-	0.004 [e,g]	0.0004 [e,g]
Diethyl Phthalate	000084-66-2	- [k]	-	-	168 [b,g]	17 [b,g]
Dimethylphenol, 2,4-	000105-67-9	40,880 [b]	-	-	12 [b,g]	1 [b,g]
Dinitro-o-cresol, 4,6-	000534-52-1	204 [b]	-	-	0.09 [b,g]	0.009 [b,g]
Dinitrophenol, 2,4-	000051-28-5	4,088 [b]	-	-	0.2 [b,g]	0.1 [b,g]
Dinitrotoluene, 2,4-	000121-14-2	7 [e]	-	-	0.006 [e,g]	0.0006 [e,g]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont’d)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					DF = 10	**DF = 1**
Dinitrotoluene, 2,6-	000606-20-2	2,044 [b]	-	-	0.7 [b,g]	0.07 [b,g]
Diphenylhydrazine, 1,2-	000122-66-7	3 [e]	-	-	0.006 [e,g]	0.0006 [e,g]
Endosulfan	000115-29-7	12,264 [b]	-	-	42 [b,g]	4 [b,g]
Endrin	000072-20-8	613 [b]	-	-	0.2 [h]	0.02 [h]
Ethylbenzene	000100-41-4	186 [c,e]	-	-	3 [h]	0.3 [h]
Fluoranthene	000206-44-0	81,760 [b]	-	-	2,273 [b,g]	227 [b,g]
Fluorene	000086-73-7	81,760 [b]	-	-	379 [b,g]	38 [b,g]
Furan	000110-00-9	2,044 [b,c]	-	-	0.2 [b,g]	0.02 [b,g]
Heptachlor	000076-44-8	0.5 [e]	-	-	0.03 [e,g]	0.003 [e,g]
Heptachlor Epoxide	001024-57-3	0.2 [e]	-	-	0.003 [e,g]	0.0003 [e,g]
Hexachlorobenzene	000118-74-1	1 [e]	-	-	0.01 [e,g]	0.001 [e,g]
Hexachlorobutadiene	000087-68-3	26 [e]	-	-	0.01 [h]	0.001 [h]
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	0.3 [e]	-	-	0.001 [e,g]	0.0001 [e,g]
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	1 [e]	-	-	0.005 [e,g]	0.0005 [e,g]
Hexachlorocyclohexane, Gamma- (γ-HCH)	000058-89-9	2 [e]	-	-	0.1 [h]	0.01 [h]
Hexachlorocyclopentadiene	000077-47-4	12,264 [b]	-	-	9 [b,g]	1 [b,g]
Hexachloroethane	000067-72-1	146 [e]	-	-	0.06 [e,g]	0.006 [e,g]
Indeno[1,2,3-cd]pyrene	000193-39-5	3 [e]	-	-	8 [e,g]	0.8 [e,g]
Isophorone	000078-59-1	2,152 [e]	-	-	0.5 [e,g]	0.05 [e,g]
MCPA	000094-74-6	1,022 [b]	-	-	0.005 [h]	0.0005 [h]
Maneb	012427-38-2	10,220 [b]	-	-	4 [b,g]	0.4 [b,g]
Methoxychlor	000072-43-5	10,220 [b]	-	-	11 [h]	1 [h]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont'd)

Compound	CAS No.	Ingestion - Dermal (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Groundwater [l] (mg/kg)	
					DF = 10	DF = 1
Methyl tert-Butyl Ether (MTBE)	001634-04-4	1,136 [c,e]	-	-	0.2 [e,g]	0.02 [e,g]
Methylene Chloride	000075-09-2	273 [c,e]	-	-	0.05 [h]	0.005 [h]
Mirex	002385-85-5	0.1 [e]	-	-	0.06 [e,g]	0.006 [e,g]
Naphthalene	000091-20-3	40,880 [b]	-	-	34 [b,g]	3 [b,g]
Nitrobenzene	000098-95-3	4,088 [b,c]	-	-	0.7 [b,g]	0.07 [b,g]
Nitroso-di-N-propylamine, N-	000621-64-7	0.3 [e]	-	-	0.0002 [e,g]	0.00002 [e,g]
Nitrosodimethylamine, N-	000062-75-9	0.04 [e]	-	-	0.2 [h]	0.02 [h]
Nitrosodiphenylamine, N-	000086-30-6	417 [e]	-	-	2 [e,g]	0.2 [e,g]
Pentachlorobenzene	000608-93-5	1,635 [b]	-	-	3 [b,g]	0.3 [b,g]
Pentachlorophenol	000087-86-5	5 [e]	-	-	0.004 [e,g]	0.0004 [e,g]
Phenol	000108-95-2	613,200 [b]	-	-	88 [b,g]	9 [b,g]
Polychlorinated Biphenyls (high risk) [m]	001336-36-3	1 [e]	-	-	0.1 [e,g]	0.01 [e,g]
Polychlorinated Biphenyls (low risk) [n]	001336-36-3	5 [e]	-	-	0.6 [e,g]	0.06 [e,g]
Pyrene	000129-00-0	61,320 [b]	-	-	1,668 [b,g]	167 [b,g]
Pyridine	000110-86-1	2,044 [b,c]	-	-	0.2 [b,g]	0.02 [b,g]
Styrene	000100-42-5	408,800 [b,c]	-	-	0.2 [h]	0.02 [h]
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	613 [b]	-	-	0.7 [b,g]	0.07 [b,g]
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	0.00002 [e]	-	-	0.000005 [e,g]	0.0000005 [e,g]
Tetrachloroethane, 1,1,1,2-	000630-20-6	79 [c,e]	-	-	0.02 [e,g]	0.002 [e,g]
Tetrachloroethylene	000127-18-4	4 [c,e]	-	-	0.2 [h]	0.02 [h]
Toluene	000108-88-3	163,520 [b,c]	-	-	5 [h]	0.5 [h]
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35) [o]	000000-00-9	- [k]	-	-	204 [b,g]	20 [b,g]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont’d)

Compound	CAS No.	Ingestion - Dermal (mg/kg)	Inhalation of Volatiles (mg/kg)	Inhalation of Fugitive Particulates (mg/kg)	Migration to Groundwater [l] (mg/kg)	
					DF = 10	DF = 1
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8) [o]	000000-01-0	122,640 [b,c]	-	-	6 [b,g]	0.6 [b,g]
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16) [o]	000000-01-1	204,400 [b,c]	-	-	10 [b,g]	1 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35) [o]	000000-01-2	61,320 [b,c]	-	-	3 [b,g]	0.3 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9) [o]	000000-01-3	408,800 [b,c]	-	-	20 [b,g]	2 [b,g]
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16) [o]	000000-01-4	40,880 [b,c]	-	-	2 [b,g]	0.2 [b,g]
Toxaphene	008001-35-2	2 [e]	-	-	0.2 [e,g]	0.02 [e,g]
Tributyltin Oxide	000056-35-9	613 [b]	-	-	7,941 [b,g]	794 [b,g]
Trichlorobenzene, 1,2,4-	000120-82-1	70 [c,e]	-	-	0.1 [e,g]	0.01 [e,g]
Trichloroethane, 1,1,1-	000071-55-6	- [k]	-	-	358 [b,g]	36 [b,g]
Trichloroethane, 1,1,2-	000079-00-5	36 [c,e]	-	-	0.008 [e,g]	0.0008 [e,g]
Trichloroethylene	000079-01-6	346 [c,e]	-	-	0.07 [h]	0.007 [h]
Trichlorophenol, 2,4,5-	000095-95-4	204,400 [b]	-	-	41 [b,g]	4 [b,g]
Trichlorophenol, 2,4,6-	000088-06-2	186 [e]	-	-	0.06 [e,g]	0.006 [e,g]
Vinyl Acetate	000108-05-4	- [k]	-	-	109 [b,g]	11 [b,g]
Vinyl Chloride	000075-01-4	3 [c,e]	-	-	0.0007 [e,g]	0.00007 [e,g]
Xylene, Mixture	001330-20-7	408,800 [b,c]	-	-	5 [h]	0.5 [h]
Xylene, m-	000108-38-3	- [f]	-	-	5 [h]	0.5 [h]
Xylene, o-	000095-47-6	- [f]	-	-	5 [h]	0.5 [h]
Xylene, p-	000106-42-3	- [f]	-	-	5 [h]	0.5 [h]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	$DF = 1$
INORGANICS						
Arsenic, Inorganic	007440-38-2	1 [e]	-	-	3 [i]	0.3 [i]
Barium	007440-39-3	408,800 [b,c]	-	-	281 [h]	28 [h]
Beryllium and compounds	007440-41-7	4,088 [b,c]	-	-	562 [b,g]	56 [b,g]
Cadmium (Diet)	007440-43-9	2,044 [b]	-	-	3 [i]	0.3 [i]
Chromium (III) (Insoluble Salts)	016065-83-1	- [k]	-	-	750,000 [i]	75,000 [i]
Chromium VI (particulates)	018540-29-9	4 [c,e]	-	-	7 [i]	0.7 [i]
Chromium, Total (1:6 ratio Cr VI : Cr III)	007440-47-3	- [f]	-	-	750,000 [i]	75,000 [i]
Cobalt	007440-48-4	613 [b,c]	-	-	7 [b,g]	0.7 [b,g]
Copper	007440-50-8	81,760 [b,c]	-	-	704 [i]	70 [i]
Cyanide (CN-)	000057-12-5	40,880 [b,c]	-	-	5 [i]	0.5 [i]
Lead and Compounds	007439-92-1	400 [p]	-	-	90 [i]	9 [i]
Mercury (elemental)	007439-97-6	327 [b,c]	0.5 [b]	-	0.4 [i]	0.04 [i]
Molybdenum	007439-98-7	10,220 [b,c]	-	-	14 [h]	1 [h]
Nickel Soluble Salts	007440-02-0	40,880 [b,c]	-	-	12 [i]	1 [i]
Selenium	007782-49-2	10,220 [b,c]	-	-	0.2 [i]	0.02 [i]
Silver	007440-22-4	10,220 [b,c]	-	-	17 [b,g]	2 [b,g]
Tetraethyl Lead	000078-00-2	0.2 [b]	-	-	0.0002 [b,g]	0.00002 [b,g]
Thallium (Soluble Salts)	007440-28-0	20 [b,c]	-	-	0.4 [b,g]	0.04 [b,g]
Thiocyanate	000463-56-9	409 [b,c]	-	-	0.02 [b,g]	0.002 [b,g]
Tin	007440-31-5	- [k]	-	-	76,711 [b,g]	7,671 [b,g]
Titanium Tetrachloride	007550-45-0	- [f]	-	-	- [f]	- [f]

Table D.3 Generic SQSs for Commercial/Industrial Land Use: Indoor Worker (cont'd)

Compound	**CAS No.**	**Ingestion - Dermal (mg/kg)**	**Inhalation of Volatiles (mg/kg)**	**Inhalation of Fugitive Particulates (mg/kg)**	**Migration to Groundwater [l] (mg/kg)**	
					$DF = 10$	$DF = 1$
Vanadium, Metallic	007440-62-2	143 [b,c]	-	-	36 [b,g]	4 [b,g]
Zinc (Metallic)	007440-66-6	613,200 [b,c]	-	-	8,922 [b,g]	892 [b,g]

a) SQSs are calculated based on human health criteria only.
b) Calculated values correspond to a noncancer hazard quotient of 1.
c) No dermal absorption data available; calculated based on ingestion data only.
d) Soil saturation concentration (C_{sat}).
e) Calculated values correspond to a cancer risk of 1/1.000.000.
f) No toxicity criteria available.
g) SQS is based on HBL (Health Based Limit).
h) SQS is based on WHO Drinking Water Standards (WHO, 2008).
i) SQS is based on TS-266 Standards (TSE, 2005).
j) SQS cannot be calculated since D_i and D_w values are not available for this compound.
k) Chemical-specific properties are such that this pathway is not of concern at any soil contaminant concentration.
l) If depth to aquifer is less than 3m, or aquifer is fractured or carstic, or source area is greater than or equal to 10ha, then DF is taken as 1; in other conditions DF is taken as 10.
m) For PCB mixtures other than Aroclor 1016.
n) Only for mixtures of Aroclor 1016.
o) EC: Equivalent carbon number.
p) SQS is adopted from US EPA, 1994.

APPENDIX-E

CHEMICAL SPECIFIC DATA USED FOR DERIVATION OF SOIL QUALITY STANDARDS

Chemical specific data used in calculation of SQSs are given in the following tables:

- Table E.1 Human Health Benchmark Values
- Table E.2 Chemical Specific Properties
- Table E.3 Physical State of Organic Chemicals at Typical Soil Temperatures
- Table E.4 Cancer Classification and Target Organ/System

Table E.1 Human Health Benchmark Values (URL 3)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w)** [d] **(mg/L)**	**Oral Reference Dose (RfD_o) (mg/kg.d)**	**Oral Cancer Slope Factor (SF_o) $(mg/kg.d)^{-1}$**	**Inhalation Reference Concentration (RfC) (mg/m^3)**	**Inhalation Unit Risk Factor (URF) $(mg/m^3)^{-1}$**	**Gastro-intestinal Absorption Factor (ABS_{GI}) (unitless)**	**Dermal Absorption Factor (ABS_d) (unitless)**
ORGANICS								
Acenaphthene	000083-32-9	2.19E+00 [a]	6.00E-02	-	-	-	1.00E+00	1.30E-01
Acetone	000067-64-1	3.29E+01 [a]	9.00E-01	-	3.09E+01	-	1.00E+00	-
Acrolein	000107-02-8	1.83E-02 [a]	5.00E-04	-	2.00E-05	-	1.00E+00	-
Acrylamide	000079-06-1	1.34E-04 [a]	2.00E-03	5.00E-01	6.00E-03	1.00E-01	1.00E+00	1.00E-01
Acrylonitrile	000107-13-1	1.25E-04 [a]	4.00E-02	5.40E-01	2.00E-03	6.80E-02	1.00E+00	-
Aldrin	000309-00-2	3.96E-06 [a]	3.00E-05	1.70E+01	-	4.90E+00	1.00E+00	1.00E-01
Anthracene	000120-12-7	1.10E+01 [a]	3.00E-01	-	-	-	1.00E+00	1.30E-01
Atrazine	001912-24-9	2.00E-03 [b]	3.50E-02	2.30E-01	-	-	1.00E+00	1.00E-01
Benz[a]anthracene	000056-55-3	9.21E-05 [a]	-	7.30E-01	-	1.10E-01	1.00E+00	1.30E-01
Benzene	000071-43-2	1.00E-03 [c]	4.00E-03	5.50E-02	3.00E-02	7.80E-03	1.00E+00	-
Benzidine	000092-87-5	2.92E-07 [a]	3.00E-03	2.30E+02	-	6.70E+01	1.00E+00	1.00E-01
Benzo[a]pyrene	000050-32-8	9.21E-06 [a]	-	7.30E+00	-	1.10E+00	1.00E+00	1.30E-01
Benzo[b]fluoranthene	000205-99-2	9.21E-05 [a]	-	7.30E-01	-	1.10E-01	1.00E+00	1.30E-01
Benzo[k]fluoranthene	000207-08-9	9.21E-04 [a]	-	7.30E-02	-	1.10E-01	1.00E+00	1.30E-01
Benzoic Acid	000065-85-0	1.46E+02 [a]	4.00E+00	-	-	-	1.00E+00	1.00E-01
Bis(2-chloroethoxy)methane	000111-91-1	1.10E-01 [a]	3.00E-03	-	-	-	1.00E+00	1.00E-01
Bis(2-chloroethyl)ether	000111-44-4	6.11E-05 [a]	-	1.10E+00	-	3.30E-01	1.00E+00	-
Bis(2-ethylhexyl)phthalate	000117-81-7	8.00E-03 [b]	2.00E-02	1.40E-02	-	2.40E-03	1.00E+00	1.00E-01
Bis(chloromethyl)ether	000542-88-1	3.06E-07 [a]	-	2.20E+02	-	6.20E+01	1.00E+00	-
Bromodichloromethane	000075-27-4	1.08E-03 [a]	2.00E-02	6.20E-02	-	3.70E-02	1.00E+00	-
Bromoform	000075-25-2	1.00E-01 [b]	2.00E-02	7.90E-03	-	1.10E-03	1.00E+00	1.00E-01
Bromomethane	000074-83-9	5.11E-02 [a]	1.40E-03	-	5.00E-03	-	1.00E+00	-

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w) [d] (mg/L)**	**Oral Reference Dose (RfD_o) (mg/kg.d)**	**Oral Cancer Slope Factor (SF_o) $(mg/kg.d)^{-1}$**	**Inhalation Reference Concentration (RfC) (mg/m^3)**	**Inhalation Unit Risk Factor (URF) $(mg/m^3)^{-1}$**	**Gastro-intestinal Absorption Factor (ABS_{GI}) (unitless)**	**Dermal Absorption Factor (ABS_d) (unitless)**
Butanol, N-	000071-36-3	3.65E+00 [a]	1.00E-01	-	-	-	1.00E+00	1.00E-01
Butyl Benzyl Phthlate	000085-68-7	3.54E-02 [a]	2.00E-01	1.90E-03	-	-	1.00E+00	1.00E-01
Carbaryl	000063-25-2	3.65E+00 [a]	1.00E-01	-	-	-	1.00E+00	1.00E-01
Carbazole	000086-74-8	3.36E-03 [a]	-	2.00E-02	-	-	1.00E+00	1.00E-01
Carbofuran	001563-66-2	7.00E-03 [b]	5.00E-03	-	-	-	1.00E+00	1.00E-01
Carbon Disulfide	000075-15-0	3.65E+00 [a]	1.00E-01	-	7.00E-01	-	1.00E+00	-
Carbon Tetrachloride	000056-23-5	4.00E-03 [b]	7.00E-04	1.30E-01	1.89E-01	1.50E-02	1.00E+00	-
Chlordane	012789-03-6	2.00E-04 [b]	5.00E-04	3.50E-01	7.00E-04	1.00E-01	1.00E+00	4.00E-02
Chloroaniline, p-	000106-47-8	3.36E-04 [a]	4.00E-03	2.00E-01	-	-	1.00E+00	1.00E-01
Chlorobenzene	000108-90-7	7.30E-01 [a]	2.00E-02	-	5.00E-02	-	1.00E+00	-
Chloroform	000067-66-3	3.00E-01 [b]	1.00E-02	3.10E-02	9.77E-02	2.30E-02	1.00E+00	-
Chloromethane	000074-87-3	-	-	-	9.00E-02	-	1.00E+00	-
Chloronaphthalene, Beta-	000091-58-7	2.92E+00 [a]	8.00E-02	-	-	-	1.00E+00	-
Chlorophenol, 2-	000095-57-8	1.83E-01 [a]	5.00E-03	-	-	-	1.00E+00	-
Chrysene	000218-01-9	9.21E-03 [a]	-	7.30E-03	-	1.10E-02	1.00E+00	1.30E-01
Cresol, m-	000108-39-4	1.83E+00 [a]	5.00E-02	-	6.00E-01	-	1.00E+00	1.00E-01
Cresol, o-	000095-48-7	1.83E+00 [a]	5.00E-02	-	6.00E-01	-	1.00E+00	1.00E-01
Cresol, p-	000106-44-5	1.83E-01 [a]	5.00E-03	-	6.00E-01	-	1.00E+00	1.00E-01
Cyclohexanone	000108-94-1	1.83E+02 [a]	5.00E+00	-	-	-	1.00E+00	1.00E-01
DDD	000072-54-8	1.00E-03 [b]	-	2.40E-01	-	6.90E-02	1.00E+00	1.00E-01
DDE, p,p'-	000072-55-9	1.00E-03 [b]	-	3.40E-01	-	9.70E-02	1.00E+00	1.00E-01
DDT	000050-29-3	1.00E-03 [b]	5.00E-04	3.40E-01	-	9.70E-02	1.00E+00	3.00E-02
Dibenz[a,h]anthracene	000053-70-3	9.21E-06 [a]	-	7.30E+00	-	1.20E+00	1.00E+00	1.30E-01

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w) [d] (mg/L)**	**Oral Reference Dose (RfD_o) (mg/kg.d)**	**Oral Cancer Slope Factor (SF_o) $(mg/kg.d)^{-1}$**	**Inhalation Reference Concentration (RfC) (mg/m^3)**	**Inhalation Unit Risk Factor (URF) $(mg/m^3)^{-1}$**	**Gastro-intestinal Absorption Factor (ABS_{GI}) (unitless)**	**Dermal Absorption Factor (ABS_d) (unitless)**
Dibromochloromethane	000124-48-1	1.00E-01 [b]	2.00E-02	8.40E-02	-	2.70E-02	1.00E+00	1.00E-01
Dibutyl Phthalate	000084-74-2	3.65E+00 [a]	1.00E-01	-	-	-	1.00E+00	1.00E-01
Dichlorobenzene, 1,2-	000095-50-1	1.00E+00 [b]	9.00E-02	-	2.00E-01	-	1.00E+00	-
Dichlorobenzene, 1,4-	000106-46-7	3.00E-01 [b]	7.00E-02	5.40E-03	8.00E-01	1.10E-02	1.00E+00	-
Dichlorobenzidine, 3,3'-	000091-94-1	1.49E-04 [a]	-	4.50E-01	-	3.40E-01	1.00E+00	1.00E-01
Dichloroethane, 1,1-	000075-34-3	1.18E-02 [a]	2.00E-01	5.70E-03	-	1.60E-03	1.00E+00	-
Dichloroethane, 1,2-	000107-06-2	7.39E-04 [a]	2.00E-02	9.10E-02	2.43E+00	2.60E-02	1.00E+00	-
Dichloroethylene, 1,1-	000075-35-4	1.83E+00 [a]	5.00E-02	-	2.00E-01	-	1.00E+00	-
Dichloroethylene, 1,2-cis-	000156-59-2	5.00E-02 [b]	2.00E-03	-	-	-	1.00E+00	-
Dichloroethylene, 1,2-trans-	000156-60-5	7.30E-01 [a]	2.00E-02	-	6.00E-02	-	1.00E+00	-
Dichlorophenol, 2,4-	000120-83-2	1.10E-01 [a]	3.00E-03	-	-	-	1.00E+00	1.00E-01
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	3.00E-02 [b]	1.00E-02	-	-	-	1.00E+00	5.00E-02
Dichloropropane, 1,2-	000078-87-5	4.00E-02 [b]	9.00E-02	3.60E-02	4.00E-03	1.00E-02	1.00E+00	-
Dichloropropene, 1,3-	000542-75-6	6.72E-04 [a]	3.00E-02	1.00E-01	2.00E-02	4.00E-03	1.00E+00	-
Dieldrin	000060-57-1	4.20E-06 [a]	5.00E-05	1.60E+01	-	4.60E+00	1.00E+00	1.00E-01
Diethyl Phthalate	000084-66-2	2.92E+01 [a]	8.00E-01	-	-	-	1.00E+00	1.00E-01
Dimethylphenol, 2,4-	000105-67-9	7.30E-01 [a]	2.00E-02	-	-	-	1.00E+00	1.00E-01
Dinitro-o-cresol, 4,6-	000534-52-1	3.65E-03 [a]	1.00E-04	-	-	-	1.00E+00	1.00E-01
Dinitrophenol, 2,4-	000051-28-5	7.30E-02 [a]	2.00E-03	-	-	-	1.00E+00	1.00E-01
Dinitrotoluene, 2,4-	000121-14-2	2.17E-04 [a]	2.00E-03	3.10E-01	-	8.90E-02	1.00E+00	1.02E-01
Dinitrotoluene, 2,6-	000606-20-2	3.65E-02 [a]	1.00E-03	-	-	-	1.00E+00	9.90E-02
Diphenylhydrazine, 1,2-	000122-66-7	8.40E-05 [a]	-	8.00E-01	-	2.20E-01	1.00E+00	1.00E-01
Endosulfan	000115-29-7	2.19E-01 [a]	6.00E-03	-	-	-	1.00E+00	1.00E-01

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w) [d] (mg/L)**	**Oral Reference Dose (RfD_o) (mg/kg.d)**	**Oral Cancer Slope Factor (SF_o) $(mg/kg.d)^{-1}$**	**Inhalation Reference Concentration (RfC) (mg/m^3)**	**Inhalation Unit Risk Factor (URF) $(mg/m^3)^{-1}$**	**Gastro-intestinal Absorption Factor (ABS_{GI}) (unitless)**	**Dermal Absorption Factor (ABS_d) (unitless)**
Endrin	000072-20-8	6.00E-04 [b]	3.00E-04	-	-	-	1.00E+00	1.00E-01
Ethylbenzene	000100-41-4	3.00E-01 [b]	1.00E-01	1.10E-02	1.00E+00	2.50E-03	1.00E+00	-
Fluoranthene	000206-44-0	1.46E+00 [a]	4.00E-02	-	-	-	1.00E+00	1.30E-01
Fluorene	000086-73-7	1.46E+00 [a]	4.00E-02	-	-	-	1.00E+00	1.30E-01
Furan	000110-00-9	3.65E-02 [a]	1.00E-03	-	-	-	1.00E+00	-
Heptachlor	000076-44-8	1.49E-05 [a]	5.00E-04	4.50E+00	-	1.30E+00	1.00E+00	1.00E-01
Heptachlor Epoxide	001024-57-3	7.39E-06 [a]	1.30E-05	9.10E+00	-	2.60E+00	1.00E+00	1.00E-01
Hexachlorobenzene	000118-74-1	4.20E-05 [a]	8.00E-04	1.60E+00	-	4.60E-01	1.00E+00	1.00E-01
Hexachlorobutadiene	000087-68-3	6.00E-04 [b]	1.00E-03	7.80E-02	-	2.20E-02	1.00E+00	1.00E-01
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	1.07E-05 [a]	8.00E-03	6.30E+00	-	1.80E+00	1.00E+00	1.00E-01
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	3.74E-05 [a]	-	1.80E+00	-	5.30E-01	1.00E+00	1.00E-01
Hexachlorocyclohexane, Gamma- (γ-HCH)	000058-89-9	2.00E-03 [b]	3.00E-04	1.10E+00	-	3.10E-01	1.00E+00	4.00E-02
Hexachlorocyclopentadiene	000077-47-4	2.19E-01 [a]	6.00E-03	-	2.00E-04	-	1.00E+00	1.00E-01
Hexachloroethane	000067-72-1	4.80E-03 [a]	1.00E-03	1.40E-02	-	4.00E-03	1.00E+00	1.00E-01
Indeno[1,2,3-cd]pyrene	000193-39-5	9.21E-05 [a]	-	7.30E-01	-	1.10E-01	1.00E+00	1.30E-01
Isophorone	000078-59-1	7.08E-02 [a]	2.00E-01	9.50E-04	2.00E+00	-	1.00E+00	1.00E-01
MCPA	000094-74-6	2.00E-03 [b]	5.00E-04	-	-	-	1.00E+00	1.00E-01
Maneb	012427-38-2	1.83E-01 [a]	5.00E-03	-	-	-	1.00E+00	1.00E-01
Methoxychlor	000072-43-5	2.00E-02 [b]	5.00E-03	-	-	-	1.00E+00	1.00E-01
Methyl tert-Butyl Ether (MTBE)	001634-04-4	3.74E-02 [a]	-	1.80E-03	3.00E+00	2.60E-04	1.00E+00	-
Methylene Chloride	000075-09-2	2.00E-02 [b]	6.00E-02	7.50E-03	1.04E+00	4.70E-04	1.00E+00	-

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w) [d] (mg/L)**	**Oral Reference Dose (RfD_o) (mg/kg.d)**	**Oral Cancer Slope Factor (SF_o) (mg/kg.d)$^{-1}$**	**Inhalation Reference Concentration (RfC) (mg/m^3)**	**Inhalation Unit Risk Factor (URF) (mg/m^3)$^{-1}$**	**Gastro-intestinal Absorption Factor (ABS_{GI}) (unitless)**	**Dermal Absorption Factor (ABS_d) (unitless)**
Mirex	002385-85-5	3.74E-06 [a]	2.00E-04	1.80E+01	-	5.10E+00	1.00E+00	1.00E-01
Naphthalene	000091-20-3	7.30E-01 [a]	2.00E-02	-	3.00E-03	3.40E-02	1.00E+00	1.30E-01
Nitrobenzene	000098-95-3	7.30E-02 [a]	2.00E-03	-	9.00E-03	4.00E-02	1.00E+00	-
Nitroso-di-N-propylamine, N-	000621-64-7	9.61E-06 [a]	-	7.00E+00	-	2.00E+00	1.00E+00	1.00E-01
Nitrosodimethylamine, N-	000062-75-9	1.00E-01 [b]	8.00E-06	5.10E+01	4.00E-05	1.40E+01	1.00E+00	1.00E-01
Nitrosodiphenylamine, N-	000086-30-6	1.37E-02 [a]	-	4.90E-03	-	2.60E-03	1.00E+00	1.00E-01
Pentachlorobenzene	000608-93-5	2.92E-02 [a]	8.00E-04	-	-	-	1.00E+00	1.00E-01
Pentachlorophenol	000087-86-5	1.68E-04 [a]	5.00E-03	4.00E-01	-	5.10E-03	1.00E+00	2.50E-01
Phenol	000108-95-2	1.10E+01 [a]	3.00E-01	-	2.00E-01	-	1.00E+00	1.00E-01
Polychlorinated Biphenyls (high risk)	001336-36-3	3.36E-05 [a]	-	2.00E+00	-	5.70E-01	1.00E+00	1.40E-01
Polychlorinated Biphenyls (low risk)	001336-36-3	1.68E-04 [a]	-	4.00E-01	-	1.00E-01	1.00E+00	1.40E-01
Pyrene	000129-00-0	1.10E+00 [a]	3.00E-02	-	-	-	1.00E+00	1.30E-01
Pyridine	000110-86-1	3.65E-02 [a]	1.00E-03	-	-	-	1.00E+00	-
Styrene	000100-42-5	2.00E-02 [b]	2.00E-01	-	1.00E+00	-	1.00E+00	-
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	1.10E-02 [a]	3.00E-04	-	-	-	1.00E+00	1.00E-01
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	5.17E-10 [a]	1.00E-09	1.30E+05	4.00E-08	3.80E+04	1.00E+00	3.00E-02
Tetrachloroethane, 1,1,1,2-	000630-20-6	2.59E-03 [a]	3.00E-02	2.60E-02	-	7.40E-03	1.00E+00	-
Tetrachloroethylene	000127-18-4	4.00E-02 [b]	1.00E-02	5.40E-01	2.71E-01	5.90E-03	1.00E+00	-
Toluene	000108-88-3	7.00E-01 [b]	8.00E-02	-	5.00E+00	-	1.00E+00	-
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35) [e]	000000-00-9	7.30E+01 [a]	2.00E+00	-	-	-	1.00E+00	-

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w) [d] (mg/L)**	**Oral Reference Dose (RfD_o) (mg/kg.d)**	**Oral Cancer Slope Factor (SF_o) (mg/kg.d)$^{-1}$**	**Inhalation Reference Concentration (RfC) (mg/m^3)**	**Inhalation Unit Risk Factor (URF) (mg/m^3)$^{-1}$**	**Gastro-intestinal Absorption Factor (ABS_{GI}) (unitless)**	**Dermal Absorption Factor (ABS_d) (unitless)**
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8) [e]	000000-01-0	2.19E+00 [a]	6.00E-02	-	2.00E-01	-	1.00E+00	-
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16) [e]	000000-01-1	3.65E+00 [a]	1.00E-01	-	1.00E+00	-	1.00E+00	-
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35) [e]	000000-01-2	1.10E+00 [a]	3.00E-02	-	-	-	1.00E+00	-
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9) [e]	000000-01-3	7.30E+00 [a]	2.00E-01	-	4.00E-01	-	1.00E+00	-
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16) [e]	000000-01-4	7.30E-01 [a]	2.00E-02	-	2.00E-01	-	1.00E+00	-
Toxaphene	008001-35-2	6.11E-05 [a]	-	1.10E+00	-	3.20E-01	1.00E+00	1.00E-01
Tributyltin Oxide	000056-35-9	1.10E-02 [a]	3.00E-04	-	-	-	1.00E+00	1.00E-01
Trichlorobenzene, 1,2,4-	000120-82-1	2.32E-03 [a]	1.00E-02	2.90E-02	2.00E-03	-	1.00E+00	-
Trichloroethane, 1,1,1-	000071-55-6	7.30E+01 [a]	2.00E+00	-	5.00E+00	-	1.00E+00	-
Trichloroethane, 1,1,2-	000079-00-5	1.18E-03 [a]	4.00E-03	5.70E-02	-	1.60E-02	1.00E+00	-
Trichloroethylene	000079-01-6	2.00E-02 [b]	-	5.90E-03	-	2.00E-03	1.00E+00	-
Trichlorophenol, 2,4,5-	000095-95-4	3.65E+00 [a]	1.00E-01	-	-	-	1.00E+00	1.00E-01
Trichlorophenol, 2,4,6-	000088-06-2	6.11E-03 [a]	1.00E-03	1.10E-02	-	3.10E-03	1.00E+00	1.00E-01
Vinyl Acetate	000108-05-4	3.65E+01 [a]	1.00E+00	-	2.00E-01	-	1.00E+00	-
Vinyl Chloride	000075-01-4	9.34E-05 [a]	3.00E-03	7.20E-01	1.00E-01	4.40E-03	1.00E+00	-
Xylene, Mixture	001330-20-7	5.00E-01 [b]	2.00E-01	-	1.00E-01	-	1.00E+00	-
Xylene, m-	000108-38-3	5.00E-01 [b]	-	-	7.00E-01	-	1.00E+00	-
Xylene, o-	000095-47-6	5.00E-01 [b]	-	-	7.00E-01	-	1.00E+00	-
Xylene, p-	000106-42-3	5.00E-01 [b]	-	-	7.00E-01	-	1.00E+00	-

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (*C_w*) [d] (mg/L)**	**Oral Reference Dose (*RfD_o*) (mg/kg.d)**	**Oral Cancer Slope Factor (*SF_o*) (mg/kg.d)$^{-1}$**	**Inhalation Reference Concentration (*RfC*) (mg/m^3)**	**Inhalation Unit Risk Factor (*URF*) (mg/m^3)$^{-1}$**	**Gastro-intestinal Absorption Factor (*ABS_{GI}*) (unitless)**	**Dermal Absorption Factor (*ABS_d*) (unitless)**
INORGANICS								
Arsenic, Inorganic	007440-38-2	1.00E-02 [c]	3.00E-04	1.50E+00	1.50E-05	4.30E+00	1.00E+00	3.00E-02
Barium	007440-39-3	7.00E-01 [b]	2.00E-01	-	5.00E-04	-	7.00E-02	-
Beryllium and compounds	007440-41-7	7.30E-02 [a]	2.00E-03	-	2.00E-05	2.40E+00	7.00E-03	-
Cadmium (Diet)	007440-43-9	5.00E-03 [c]	1.00E-03	-	1.00E-05	1.80E+00	2.50E-02	1.00E-03
Chromium (III) (Insoluble Salts)	016065-83-1	5.00E-02 [c]	1.50E+00	-	-	-	1.30E-02	-
Chromium VI (particulates)	018540-29-9	5.00E-02 [c]	3.00E-03	5.00E-01	1.00E-04	8.40E+01	2.50E-02	-
Chromium, Total (1:6 ratio Cr VI : Cr III)	007440-47-3	5.00E-02 [c]	-	-	-	1.20E+01	1.30E-02	-
Cobalt	007440-48-4	1.10E-02 [a]	3.00E-04	-	6.00E-06	9.00E+00	1.00E+00	-
Copper	007440-50-8	2.00E+00 [c]	4.00E-02	-	-	-	1.00E+00	-
Cyanide (CN-)	000057-12-5	5.00E-02 [c]	2.00E-02	-	-	-	1.00E+00	-
Lead and Compounds	007439-92-1	1.00E-02 [c]	-	-	-	-	1.00E+00	-
Mercury (elemental)	007439-97-6	1.00E-03 [c]	1.60E-04	-	3.00E-04	-	1.00E+00	-
Molybdenum	007439-98-7	7.00E-02 [b]	5.00E-03	-	-	-	1.00E+00	-
Nickel Soluble Salts	007440-02-0	2.00E-02 [c]	2.00E-02	-	9.00E-05	2.60E-01	4.00E-02	-
Selenium	007782-49-2	1.00E-02 [c]	5.00E-03	-	2.00E-02	-	1.00E+00	-
Silver	007440-22-4	1.83E-01 [a]	5.00E-03	-	-	-	4.00E-02	-
Tetraethyl Lead	000078-00-2	3.65E-06 [a]	1.00E-07	-	-	-	1.00E+00	1.00E-01
Thallium (Soluble Salts)	007440-28-0	3.65E-04 [a]	1.00E-05	-	-	-	1.00E+00	-
Thiocyanate	000463-56-9	7.30E-03 [a]	2.00E-04	-	-	-	1.00E+00	-
Tin	007440-31-5	2.19E+01 [a]	6.00E-01	-	-	-	1.00E+00	-
Titanium Tetrachloride	007550-45-0	-	-	-	1.00E-04	-	1.00E+00	-

Table E.1 Human Health Benchmark Values (URL 3) (cont'd)

Compound	**CAS No.**	**Acceptable Groundwater Concentration (C_w) [d]** (mg/L)	**Oral Reference Dose (RfD_o)** (mg/kg.d)	**Oral Cancer Slope Factor (SF_o)** $(mg/kg.d)^{-1}$	**Inhalation Reference Concentration (RfC)** (mg/m^3)	**Inhalation Unit Risk Factor (URF)** $(mg/m^3)^{-1}$	**Gastro-intestinal Absorption Factor (ABS_{GI})** (unitless)	**Dermal Absorption Factor (ABS_d)** (unitless)
Vanadium, Metallic	007440-62-2	2.56E-03 [a]	7.00E-05	-	-	-	2.60E-02	-
Zinc (Metallic)	007440-66-6	1.10E+01 [a]	3.00E-01	-	-	-	1.00E+00	-

a) Health Based Limit (HBL) (for residential scenario).

b) World Health Organization's (WHO's) Drinking Water Standard (WHO, 2008).

c) TS-266 Standard (TSE, 2005).

d) Acceptable groundwater concentration should be multiplied by the corresponding DF (either 1 or 10) in order to obtain C_w to be used in SQS calculations for migration to groundwater pathway.

e) EC: equivalent carbon number. Toxicological data is adopted from US EPA, 2002b.

Table E.2 Chemical Specific Properties (URL 3)

Compound	**CAS No.**	**Diffusivity in Air (D_i) (cm²/s)**	**Diffusivity in Water (D_w) (cm²/s)**	**Soil-Water Partition Coefficient (K_d) (cm³/g)**	**Henry's Law Constant (H') (unitless)**	**Organic Carbon Partition Coefficient (K_{oc}) (L/kg)**	**Water Solubility (S) (mg/L)**
ORGANICS							
Acenaphthene	000083-32-9	5.06E-02	8.33E-06	-	7.52E-03	5.03E+03	3.90E+00
Acetone	000067-64-1	1.06E-01	1.15E-05	-	1.43E-03	2.36E+00	1.00E+06
Acrolein	000107-02-8	1.12E-01	1.22E-05	-	4.99E-03	1.00E+00	2.12E+05
Acrylamide	000079-06-1	-	-	-	6.95E-08	5.69E+00	3.90E+05
Acrylonitrile	000107-13-1	1.14E-01	1.23E-05	-	5.64E-03	8.51E+00	7.45E+04
Aldrin	000309-00-2	-	-	-	1.80E-03	8.20E+04	1.70E-02
Anthracene	000120-12-7	3.90E-02	7.85E-06	-	2.27E-03	1.64E+04	4.34E-02
Atrazine	001912-24-9	-	-	-	9.65E-08	2.25E+02	3.47E+01
Benz[a]anthracene	000056-55-3	-	-	-	4.91E-04	1.77E+05	9.40E-03
Benzene	000071-43-2	8.95E-02	1.03E-05	-	2.27E-01	1.46E+02	1.79E+03
Benzidine	000092-87-5	-	-	-	2.88E-09	1.19E+03	3.22E+02
Benzo[a]pyrene	000050-32-8	-	-	-	1.87E-05	5.87E+05	1.62E-03
Benzo[b]fluoranthene	000205-99-2	-	-	-	2.69E-05	5.99E+05	1.50E-03
Benzo[k]fluoranthene	000207-08-9	-	-	-	2.39E-05	5.87E+05	8.00E-04
Benzoic Acid	000065-85-0	-	-	-	1.56E-06	5.06E-01	3.40E+03
Bis(2-chloroethoxy)methane	000111-91-1	-	-	-	1.57E-04	1.44E+01	7.80E+03
Bis(2-chloroethyl)ether	000111-44-4	5.67E-02	8.71E-06	-	6.95E-04	3.22E+01	1.72E+04
Bis(2-ethylhexyl)phthalate	000117-81-7	-	-	-	1.10E-05	1.20E+05	2.70E-01
Bis(chloromethyl)ether	000542-88-1	7.63E-02	1.04E-05	-	1.78E-01	9.70E+00	2.20E+04
Bromodichloromethane	000075-27-4	5.63E-02	1.07E-05	-	8.67E-02	3.18E+01	3.03E+03
Bromoform	000075-25-2	-	-	-	2.19E-02	3.18E+01	3.10E+03
Bromomethane	000074-83-9	1.00E-01	1.35E-05	-	3.00E-01	1.32E+01	1.52E+04

Table E.2 Chemical Specific Properties (URL 3) (cont'd)

Compound	**CAS No.**	**Diffusivity in Air (D_i)** (cm^2/s)	**Diffusivity in Water (D_w)** (cm^2/s)	**Soil-Water Partition Coefficient (K_d)** (cm^3/g)	**Henry's Law Constant (H')** (unitless)	**Organic Carbon Partition Coefficient (K_{oc})** (L/kg)	**Water Solubility (S)** (mg/L)
Butanol, N-	000071-36-3	9.00E-02	1.01E-05	-	3.60E-04	3.47E+00	6.32E+04
Butyl Benzyl Phthlate	000085-68-7	-	-	-	5.15E-05	7.16E+03	2.69E+00
Carbaryl	000063-25-2	-	-	-	1.34E-07	3.55E+02	1.10E+02
Carbazole	000086-74-8	6.26E-02	7.31E-06	-	4.74E-06	9.16E+03	1.80E+00
Carbofuran	001563-66-2	-	-	-	1.26E-07	9.53E+01	3.20E+02
Carbon Disulfide	000075-15-0	1.06E-01	1.30E-05	-	5.89E-01	2.17E+01	2.16E+03
Carbon Tetrachloride	000056-23-5	5.71E-02	9.78E-06	-	1.13E+00	4.39E+01	7.93E+02
Chlordane	012789-03-6	-	-	-	1.99E-03	3.38E+04	5.60E-02
Chloroaniline, p-	000106-47-8	7.04E-02	1.03E-05	-	4.74E-05	1.13E+02	3.90E+03
Chlorobenzene	000108-90-7	7.21E-02	9.48E-06	-	1.27E-01	2.34E+02	4.98E+02
Chloroform	000067-66-3	7.69E-02	1.09E-05	-	1.50E-01	3.18E+01	7.95E+03
Chloromethane	000074-87-3	1.24E-01	1.36E-05	-	3.61E-01	1.32E+01	5.32E+03
Chloronaphthalene, Beta-	000091-58-7	4.47E-02	7.73E-06	-	1.31E-02	2.48E+03	1.17E+01
Chlorophenol, 2-	000095-57-8	6.61E-02	9.48E-06	-	4.58E-04	2.86E+02	1.13E+04
Chrysene	000218-01-9	-	-	-	2.14E-04	1.81E+05	2.00E-03
Cresol, m-	000108-39-4	7.29E-02	9.32E-06	-	3.50E-05	3.00E+02	2.27E+04
Cresol, o-	000095-48-7	7.28E-02	9.32E-06	-	4.91E-05	3.07E+02	2.59E+04
Cresol, p-	000106-44-5	7.24E-02	9.24E-06	-	4.09E-05	3.00E+02	2.15E+04
Cyclohexanone	000108-94-1	7.68E-02	9.38E-06	-	3.68E-04	1.74E+01	2.50E+04
DDD	000072-54-8	-	-	-	2.70E-04	1.18E+05	9.00E-02
DDE, p,p'-	000072-55-9	-	-	-	1.70E-03	1.18E+05	4.00E-02
DDT	000050-29-3	-	-	-	3.40E-04	1.69E+05	5.50E-03
Dibenz[a,h]anthracene	000053-70-3	-	-	-	5.76E-06	1.91E+06	2.49E-03

Table E.2 Chemical Specific Properties (URL 3) (cont'd)

Compound	**CAS No.**	**Diffusivity in Air (D_i)** (cm^2/s)	**Diffusivity in Water (D_w)** (cm^2/s)	**Soil-Water Partition Coefficient (K_d)** (cm^3/g)	**Henry's Law Constant (H')** (unitless)	**Organic Carbon Partition Coefficient (K_{oc})** (L/kg)	**Water Solubility (S)** (mg/L)
Dibromochloromethane	000124-48-1	3.66E-02	1.06E-05	-	3.20E-02	3.18E+01	2.70E+03
Dibutyl Phthalate	000084-74-2	-	-	-	7.40E-05	1.16E+03	1.12E+01
Dichlorobenzene, 1,2-	000095-50-1	5.62E-02	8.92E-06	-	7.85E-02	3.83E+02	1.56E+02
Dichlorobenzene, 1,4-	000106-46-7	5.50E-02	8.68E-06	-	9.85E-02	3.75E+02	8.13E+01
Dichlorobenzidine, 3,3'-	000091-94-1	-	-	-	2.09E-09	3.19E+03	3.10E+00
Dichloroethane, 1,1-	000075-34-3	8.36E-02	1.06E-05	-	2.30E-01	3.18E+01	5.04E+03
Dichloroethane, 1,2-	000107-06-2	8.57E-02	1.10E-05	-	4.82E-02	3.96E+01	8.60E+03
Dichloroethylene, 1,1-	000075-35-4	8.63E-02	1.10E-05	-	1.07E+00	3.18E+01	2.42E+03
Dichloroethylene, 1,2-cis-	000156-59-2	8.84E-02	1.13E-05	-	1.67E-01	3.96E+01	6.41E+03
Dichloroethylene, 1,2-trans-	000156-60-5	8.76E-02	1.12E-05	-	1.67E-01	3.96E+01	4.52E+03
Dichlorophenol, 2,4-	000120-83-2	6.37E-02	7.44E-06	-	1.75E-04	7.17E+01	4.50E+03
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	-	-	-	1.45E-06	2.57E+01	6.77E+02
Dichloropropane, 1,2-	000078-87-5	8.13E-02	9.50E-06	-	1.15E-01	6.07E+01	2.80E+03
Dichloropropene, 1,3-	000542-75-6	8.23E-02	9.61E-06	-	1.45E-01	7.22E+01	2.80E+03
Dieldrin	000060-57-1	-	-	-	4.09E-04	2.01E+04	1.95E-01
Diethyl Phthalate	000084-66-2	-	-	-	2.49E-05	1.05E+02	1.08E+03
Dimethylphenol, 2,4-	000105-67-9	6.22E-02	8.31E-06	-	3.89E-05	4.92E+02	7.87E+03
Dinitro-o-cresol, 4,6-	000534-52-1	5.59E-02	6.53E-06	-	5.72E-05	7.54E+02	1.98E+02
Dinitrophenol, 2,4-	000051-28-5	-	-	-	3.52E-06	1.00E-02	2.79E+03
Dinitrotoluene, 2,4-	000121-14-2	-	-	-	2.21E-06	5.76E+02	2.00E+02
Dinitrotoluene, 2,6-	000606-20-2	3.70E-02	7.76E-06	-	3.05E-05	5.87E+02	1.51E+02
Diphenylhydrazine, 1,2-	000122-66-7	-	-	-	1.95E-05	1.51E+03	2.21E+02
Endosulfan	000115-29-7	-	-	-	2.66E-03	6.76E+03	3.25E-01

Table E.2 Chemical Specific Properties (URL 3) (cont'd)

Compound	**CAS No.**	**Diffusivity in Air (D_i)** (cm^2/s)	**Diffusivity in Water (D_w)** (cm^2/s)	**Soil-Water Partition Coefficient (K_d)** (cm^3/g)	**Henry's Law Constant (H')** (unitless)	**Organic Carbon Partition Coefficient (K_{oc})** (L/kg)	**Water Solubility (S)** (mg/L)
Endrin	000072-20-8	-	-	-	4.09E-04	2.01E+04	2.50E-01
Ethylbenzene	000100-41-4	6.85E-02	8.46E-06	-	3.22E-01	4.46E+02	1.69E+02
Fluoranthene	000206-44-0	-	-	-	3.62E-04	5.55E+04	2.60E-01
Fluorene	000086-73-7	4.40E-02	7.89E-06	-	3.93E-03	9.16E+03	1.69E+00
Furan	000110-00-9	1.03E-01	1.17E-05	-	2.21E-01	8.00E+01	1.00E+04
Heptachlor	000076-44-8	-	-	-	1.20E-02	4.13E+04	1.80E-01
Heptachlor Epoxide	001024-57-3	-	-	-	8.59E-04	1.01E+04	2.00E-01
Hexachlorobenzene	000118-74-1	-	-	-	6.95E-02	6.20E+03	6.20E-03
Hexachlorobutadiene	000087-68-3	-	-	-	4.21E-01	8.45E+02	3.20E+00
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	-	-	-	2.10E-04	2.81E+03	2.00E+00
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	-	-	-	2.10E-04	2.81E+03	2.40E-01
Hexachlorocyclohexane, Gamma- (γ-HCH)	000058-89-9	-	-	-	2.10E-04	2.81E+03	7.30E+00
Hexachlorocyclopentadiene	000077-47-4	-	-	-	1.10E+00	1.40E+03	1.80E+00
Hexachloroethane	000067-72-1	-	-	-	1.59E-01	1.97E+02	5.00E+01
Indeno[1,2,3-cd]pyrene	000193-39-5	-	-	-	1.42E-05	1.95E+06	1.90E-04
Isophorone	000078-59-1	5.25E-02	7.53E-06	-	2.71E-04	6.52E+01	1.20E+04
MCPA	000094-74-6	-	-	-	5.44E-08	2.96E+01	6.30E+02
Maneb	012427-38-2	-	-	-	2.31E-05	6.08E+02	1.00E+06
Methoxychlor	000072-43-5	-	-	-	8.30E-06	2.69E+04	1.00E-01
Methyl tert-Butyl Ether (MTBE)	001634-04-4	7.53E-02	8.59E-06	-	2.40E-02	1.16E+01	5.10E+04
Methylene Chloride	000075-09-2	9.99E-02	1.25E-05	-	1.33E-01	2.17E+01	1.30E+04
Mirex	002385-85-5	-	-	-	3.32E-02	3.57E+05	8.50E-02
Naphthalene	000091-20-3	6.05E-02	8.38E-06	-	1.80E-02	1.54E+03	3.10E+01

Table E.2 Chemical Specific Properties (URL 3) (cont'd)

Compound	**CAS No.**	**Diffusivity in Air** **(D_i)** **(cm^2/s)**	**Diffusivity in Water** **(D_w)** **(cm^2/s)**	**Soil-Water Partition Coefficient** **(K_d)** **(cm^3/g)**	**Henry's Law Constant** **($H^{'}$)** **(unitless)**	**Organic Carbon Partition Coefficient** **(K_{oc})** **(L/kg)**	**Water Solubility** **(S)** **(mg/L)**
Nitrobenzene	000098-95-3	6.81E-02	9.45E-06	-	9.81E-04	2.26E+02	2.09E+03
Nitroso-di-N-propylamine, N-	000621-64-7	5.64E-02	7.76E-06	-	2.20E-04	2.75E+02	1.30E+04
Nitrosodimethylamine, N-	000062-75-9	9.88E-02	1.15E-05	-	7.44E-05	2.28E+01	1.00E+06
Nitrosodiphenylamine, N-	000086-30-6	5.59E-02	6.53E-06	-	4.95E-05	2.63E+03	3.50E+01
Pentachlorobenzene	000608-93-5	-	-	-	2.87E-02	3.71E+03	8.31E-01
Pentachlorophenol	000087-86-5	-	-	-	1.00E-06	4.10E+02	1.40E+01
Phenol	000108-95-2	8.34E-02	1.03E-05	-	1.36E-05	1.87E+02	8.28E+04
Polychlorinated Biphenyls (high risk)	001336-36-3	-	-	-	7.77E-03	7.81E+04	7.00E-01
Polychlorinated Biphenyls (low risk)	001336-36-3	-	-	-	7.77E-03	7.81E+04	7.00E-01
Pyrene	000129-00-0	2.78E-02	7.25E-06	-	4.87E-04	5.43E+04	1.35E-01
Pyridine	000110-86-1	9.31E-02	1.09E-05	-	4.50E-04	7.17E+01	1.00E+06
Styrene	000100-42-5	7.11E-02	8.78E-06	-	1.12E-01	4.46E+02	3.10E+02
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	-	-	-	4.09E-02	2.22E+03	5.95E-01
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	-	-	-	2.04E-03	2.49E+05	2.00E-04
Tetrachloroethane, 1,1,1,2-	000630-20-6	4.82E-02	9.10E-06	-	1.02E-01	8.60E+01	1.07E+03
Tetrachloroethylene	000127-18-4	5.05E-02	9.46E-06	-	7.24E-01	9.49E+01	2.06E+02
Toluene	000108-88-3	7.78E-02	9.20E-06	-	2.71E-01	2.34E+02	5.26E+02
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35)	000000-00-9	-	-	-	-	-	-
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8)	000000-01-0	-	-	-	-	-	-
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16)	000000-01-1	-	-	-	-	-	-

Table E.2 Chemical Specific Properties (URL 3) (cont'd)

Compound	**CAS No.**	**Diffusivity in Air (D_i) (cm^2/s)**	**Diffusivity in Water (D_w) (cm^2/s)**	**Soil-Water Partition Coefficient (K_d) (cm^3/g)**	**Henry's Law Constant ($H^{'}$) (unitless)**	**Organic Carbon Partition Coefficient (K_{oc}) (L/kg)**	**Water Solubility (S) (mg/L)**
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35)	000000-01-2	-	-	-	-	-	-
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9)	000000-01-3	-	-	-	-	-	-
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16)	000000-01-4	-	-	-	-	-	-
Toxaphene	008001-35-2	-	-	-	2.45E-04	7.72E+04	6.97E-03
Tributyltin Oxide	000056-35-9	-	-	-	1.23E-05	2.59E+07	1.95E+01
Trichlorobenzene, 1,2,4-	000120-82-1	3.96E-02	8.40E-06	-	5.81E-02	1.36E+03	4.90E+01
Trichloroethane, 1,1,1-	000071-55-6	6.48E-02	9.60E-06	-	7.03E-01	4.39E+01	1.29E+03
Trichloroethane, 1,1,2-	000079-00-5	6.69E-02	1.00E-05	-	3.37E-02	6.07E+01	4.59E+03
Trichloroethylene	000079-01-6	6.87E-02	1.02E-05	-	4.03E-01	6.07E+01	1.28E+03
Trichlorophenol, 2,4,5-	000095-95-4	5.60E-02	6.55E-06	-	6.62E-05	2.98E+02	1.20E+03
Trichlorophenol, 2,4,6-	000088-06-2	3.14E-02	8.09E-06	-	1.06E-04	1.31E+02	8.00E+02
Vinyl Acetate	000108-05-4	8.49E-02	1.00E-05	-	2.09E-02	5.58E+00	2.00E+04
Vinyl Chloride	000075-01-4	1.07E-01	1.20E-05	-	1.14E+00	2.17E+01	8.80E+03
Xylene, Mixture	001330-20-7	8.47E-02	9.90E-06	-	2.12E-01	3.83E+02	1.06E+02
Xylene, m-	000108-38-3	6.84E-02	8.44E-06	-	2.94E-01	3.75E+02	1.61E+02
Xylene, o-	000095-47-6	6.89E-02	8.53E-06	-	2.12E-01	3.83E+02	1.78E+02
Xylene, p-	000106-42-3	6.82E-02	8.42E-06	-	2.82E-01	3.75E+02	1.62E+02
INORGANICS							
Arsenic, Inorganic	007440-38-2	-	-	2.90E+01	-	-	0.00E+00
Barium	007440-39-3	-	-	4.00E+01	-	-	0.00E+00
Beryllium and compounds	007440-41-7	-	-	5.50E+02	-	-	0.00E+00

Table E.2 Chemical Specific Properties (URL 3) (cont'd)

Compound	**CAS No.**	**Diffusivity in Air (D_i) (cm^2/s)**	**Diffusivity in Water (D_w) (cm^2/s)**	**Soil-Water Partition Coefficient (K_d) (cm^3/g)**	**Henry's Law Constant (H') (unitless)**	**Organic Carbon Partition Coefficient (K_{oc}) (L/kg)**	**Water Solubility (S) (mg/L)**
Cadmium (Diet)	007440-43-9	-	-	6.40E+01	-	-	0.00E+00
Chromium (III) (Insoluble Salts)	016065-83-1	-	-	1.50E+06	-	-	0.00E+00
Chromium VI (particulates)	018540-29-9	-	-	1.40E+01	-	-	1.69E+06
Chromium, Total (1:6 ratio Cr VI : Cr III)	007440-47-3	-	-	1.50E+06	-	-	0.00E+00
Cobalt	007440-48-4	-	-	4.50E+01	-	-	0.00E+00
Copper	007440-50-8	-	-	3.50E+01	-	-	0.00E+00
Cyanide (CN-)	000057-12-5	2.11E-01	2.46E-05	9.90E+00	5.44E-03	-	1.00E+06
Lead and Compounds	007439-92-1	-	-	9.00E+02	-	-	0.00E+00
Mercury (elemental)	007439-97-6	7.15E-02	3.01E-05	4.00E+01	1.00E+00	-	6.00E-02
Molybdenum	007439-98-7	-	-	2.00E+01	-	-	0.00E+00
Nickel Soluble Salts	007440-02-0	-	-	5.80E+01	-	-	0.00E+00
Selenium	007782-49-2	-	-	2.20E+00	-	-	0.00E+00
Silver	007440-22-4	-	-	6.60E+00	-	-	0.00E+00
Tetraethyl Lead	000078-00-2	-	-	-	2.32E+01	6.48E+02	2.90E-01
Thallium (Soluble Salts)	007440-28-0	-	-	6.90E+01	-	-	0.00E+00
Thiocyanate	000463-56-9	1.25E-01	1.46E-05	-	5.97E-03	4.67E+00	3.53E+04
Tin	007440-31-5	-	-	2.50E+02	-	-	0.00E+00
Titanium Tetrachloride	007550-45-0	-	-	-	-	-	-
Vanadium, Metallic	007440-62-2	-	-	1.00E+03	-	-	0.00E+00
Zinc (Metallic)	007440-66-6	-	-	5.80E+01	-	-	0.00E+00

* For D_i, D_w, H' and S, the values at 25°C are used.

** For ionizing organic compounds, Cr^{6+} and Se, Koc and Kd values at pH=8.0; and for the other metals (i.e. As, Ba, Be, Cd, Cr^{3+}, Hg, Ni, Ag, Tl, and Zn), Kd value at pH=6.7 is given.

Table E.3 Physical State of Organic Chemicals at Typical Soil Temperatures (URL 3)

Compound	CAS No.	Melting Point (°C)	Physical State
Acenaphthene	000083-32-9	93.4	Solid
Acetone	000067-64-1	-98.3	Liquid
Acrolein	000107-02-8	-87.7	Liquid
Acrylamide	000079-06-1	84.5	Solid
Acrylonitrile	000107-13-1	-83.5	Liquid
Aldrin	000309-00-2	240	Solid
Anthracene	000120-12-7	215	Solid
Atrazine	001912-24-9	173	Solid
Benz[a]anthracene	000056-55-3	84	Solid
Benzene	000071-43-2	5.5	Liquid
Benzidine	000092-87-5	120	Solid
Benzo[a]pyrene	000050-32-8	177	Solid
Benzo[b]fluoranthene	000205-99-2	168	Solid
Benzo[k]fluoranthene	000207-08-9	217	Solid
Benzoic Acid	000065-85-0	122	Solid
Bis(2-chloroethoxy)methane	000111-91-1	-32	Liquid
Bis(2-chloroethyl)ether	000111-44-4	-51.9	Liquid
Bis(2-ethylhexyl)phthalate	000117-81-7	-55	Liquid
Bis(chloromethyl)ether	000542-88-1	-41.5	Liquid
Bromodichloromethane	000075-27-4	-57	Liquid
Bromoform	000075-25-2	8	Liquid
Bromomethane	000074-83-9	-93.7	Liquid
Butanol, N-	000071-36-3	-89.8	Liquid
Butyl Benzyl Phthlate	000085-68-7	61.1	Solid
Carbaryl	000063-25-2	145	Solid
Carbazole	000086-74-8	246	Solid
Carbofuran	001563-66-2	151	Solid
Carbon Disulfide	000075-15-0	-112	Liquid
Carbon Tetrachloride	000056-23-5	-23	Liquid
Chlordane	012789-03-6	106	Solid
Chloroaniline, p-	000106-47-8	72.5	Solid
Chlorobenzene	000108-90-7	-45.2	Liquid
Chloroform	000067-66-3	-63.6	Liquid
Chloromethane	000074-87-3	-97.7	Liquid
Chloronaphthalene, Beta-	000091-58-7	61	Solid
Chlorophenol, 2-	000095-57-8	9.8	Liquid
Chrysene	000218-01-9	258	Solid
Cresol, m-	000108-39-4	11.8	Liquid
Cresol, o-	000095-48-7	29.8	Solid
Cresol, p-	000106-44-5	35.5	Solid
Cyclohexanone	000108-94-1	-31	Liquid
DDD	000072-54-8	110	Solid
DDE, p,p'-	000072-55-9	89	Solid
DDT	000050-29-3	109	Solid

Table E.3 Physical State of Organic Chemicals at Typical Soil Temperatures (URL 3) (cont'd)

Compound	CAS No.	Melting Point (°C)	Physical State
Dibenz[a,h]anthracene	000053-70-3	270	Solid
Dibromochloromethane	000124-48-1	-20	Liquid
Dibutyl Phthalate	000084-74-2	-35	Liquid
Dichlorobenzene, 1,2-	000095-50-1	-16.7	Liquid
Dichlorobenzene, 1,4-	000106-46-7	52.1	Solid
Dichlorobenzidine, 3,3'-	000091-94-1	132	Solid
Dichloroethane, 1,1-	000075-34-3	-96.9	Liquid
Dichloroethane, 1,2-	000107-06-2	-35.5	Liquid
Dichloroethylene, 1,1-	000075-35-4	-123	Liquid
Dichloroethylene, 1,2-cis-	000156-59-2	-57	Liquid
Dichloroethylene, 1,2-trans-	000156-60-5	-57	Liquid
Dichlorophenol, 2,4-	000120-83-2	45	Solid
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	141	Solid
Dichloropropane, 1,2-	000078-87-5	-100	Liquid
Dichloropropene, 1,3-	000542-75-6	-50	Liquid
Dieldrin	000060-57-1	226	Solid
Diethyl Phthalate	000084-66-2	-40.5	Liquid
Dimethylphenol, 2,4-	000105-67-9	24.5	Solid
Dinitro-o-cresol, 4,6-	000534-52-1	86.6	Solid
Dinitrophenol, 2,4-	000051-28-5	116	Solid
Dinitrotoluene, 2,4-	000121-14-2	71	Solid
Dinitrotoluene, 2,6-	000606-20-2	66	Solid
Diphenylhydrazine, 1,2-	000122-66-7	131	Solid
Endosulfan	000115-29-7	106	Solid
Endrin	000072-20-8	226	Solid
Ethylbenzene	000100-41-4	-94.9	Liquid
Fluoranthene	000206-44-0	108	Solid
Fluorene	000086-73-7	115	Solid
Furan	000110-00-9	-85.6	Liquid
Heptachlor	000076-44-8	95.5	Solid
Heptachlor Epoxide	001024-57-3	160	Solid
Hexachlorobenzene	000118-74-1	232	Solid
Hexachlorobutadiene	000087-68-3	-21	Liquid
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	113	Solid
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	113	Solid
Hexachlorocyclohexane, Gamma- (γ-HCH)	000058-89-9	113	Solid
Hexachlorocyclopentadiene	000077-47-4	-9	Liquid
Hexachloroethane	000067-72-1	187	Solid
Indeno[1,2,3-cd]pyrene	000193-39-5	164	Solid
Isophorone	000078-59-1	-8.1	Liquid
MCPA	000094-74-6	120	Solid
Maneb	012427-38-2	200	Solid
Methoxychlor	000072-43-5	87	Solid

Table E.3 Physical State of Organic Chemicals at Typical Soil Temperatures (URL 3) (cont'd)

Compound	**CAS No.**	**Melting Point (°C)**	**Physical State**
Methyl tert-Butyl Ether (MTBE)	001634-04-4	-109	Liquid
Methylene Chloride	000075-09-2	-95.1	Liquid
Mirex	002385-85-5	150	Solid
Naphthalene	000091-20-3	80.2	Solid
Nitrobenzene	000098-95-3	5.7	Liquid
Nitroso-di-N-propylamine, N-	000621-64-7	6.81	Liquid
Nitrosodimethylamine, N-	000062-75-9	-39.1	Liquid
Nitrosodiphenylamine, N-	000086-30-6	66.5	Solid
Pentachlorobenzene	000608-93-5	86	Solid
Pentachlorophenol	000087-86-5	174	Solid
Phenol	000108-95-2	40.9	Solid
Polychlorinated Biphenyls (high risk)	001336-36-3	122	Solid
Polychlorinated Biphenyls (low risk)	001336-36-3	122	Solid
Pyrene	000129-00-0	151	Solid
Pyridine	000110-86-1	-41.6	Liquid
Styrene	000100-42-5	-31	Liquid
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	140	Solid
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	305	Solid
Tetrachloroethane, 1,1,1,2-	000630-20-6	-70.2	Liquid
Tetrachloroethylene	000127-18-4	-22.3	Liquid
Toluene	000108-88-3	-94.9	Liquid
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35)	000000-00-9	-	Liquid
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8)	000000-01-0	-	Liquid
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16)	000000-01-1	-	Liquid
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35)	000000-01-2	-	Liquid
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9)	000000-01-3	-	Liquid
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16)	000000-01-4	-	Liquid
Toxaphene	008001-35-2	142	Solid
Tributyltin Oxide	000056-35-9	-45	Liquid
Trichlorobenzene, 1,2,4-	000120-82-1	17	Liquid
Trichloroethane, 1,1,1-	000071-55-6	-30.4	Liquid
Trichloroethane, 1,1,2-	000079-00-5	-36.6	Liquid
Trichloroethylene	000079-01-6	-84.7	Liquid
Trichlorophenol, 2,4,5-	000095-95-4	69	Solid
Trichlorophenol, 2,4,6-	000088-06-2	69	Solid
Vinyl Acetate	000108-05-4	-93.2	Liquid
Vinyl Chloride	000075-01-4	-154	Liquid
Xylene, Mixture	001330-20-7	-25.2	Liquid
Xylene, m-	000108-38-3	-47.8	Liquid
Xylene, o-	000095-47-6	-25.2	Liquid
Xylene, p-	000106-42-3	13.2	Liquid

Table E.4 Cancer Classification and Target Organ / System (URL 3)

Compound	**CAS No.**	**Cancer Classification**	**Target Organ/System**
ORGANICS			
Acenaphthene	000083-32-9	-	liver
Acetone	000067-64-1	D	liver
Acrolein	000107-02-8	C	nasal
Acrylamide	000079-06-1	B2	CNS, mamal, thyroid, uterus, oral
Acrylonitrile	000107-13-1	B1	nasal, testes, brain, spinal cord, stomach
Aldrin	000309-00-2	B2	liver
Anthracene	000120-12-7	D	-
Atrazine	001912-24-9	C	whole body, mammary gland
Benz[a]anthracene	000056-55-3	B2	-
Benzene	000071-43-2	A	blood
Benzidine	000092-87-5	A	brain, liver, bladder
Benzo[a]pyrene	000050-32-8	B2	forestomach
Benzo[b]fluoranthene	000205-99-2	B2	-
Benzo[k]fluoranthene	000207-08-9	B2	-
Benzoic Acid	000065-85-0	D	-
Bis(2-chloroethoxy)methane	000111-91-1	-	liver
Bis(2-chloroethyl)ether	000111-44-4	B2	liver
Bis(2-ethylhexyl)phthalate	000117-81-7	B2	liver
Bis(chloromethyl)ether	000542-88-1	A	respiratory system
Bromodichloromethane	000075-27-4	B2	kidney
Bromoform	000075-25-2	B2	liver, large intestine
Bromomethane	000074-83-9	D	nasal cavity, forestomach
Butanol, N-	000071-36-3	D	-
Butyl Benzyl Phthlate	000085-68-7	C	liver, brain, pancreas
Carbaryl	000063-25-2	-	kidney, liver
Carbazole	000086-74-8	-	liver
Carbofuran	001563-66-2	-	-
Carbon Disulfide	000075-15-0	-	nervous system
Carbon Tetrachloride	000056-23-5	B2	liver
Chlordane	012789-03-6	B2	liver
Chloroaniline, p-	000106-47-8	C	spleen
Chlorobenzene	000108-90-7	D	liver
Chloroform	000067-66-3	B1	liver, kidney
Chloromethane	000074-87-3	D	CNS, kidney
Chloronaphthalene, Beta-	000091-58-7	-	-
Chlorophenol, 2-	000095-57-8	-	-
Chrysene	000218-01-9	B2	-
Cresol, m-	000108-39-4	C	whole body
Cresol, o-	000095-48-7	C	whole body
Cresol, p-	000106-44-5	C	central nervous system

Table E.4 Cancer Classification and Target Organ / System (URL 3) (cont'd)

Compound	CAS No.	Cancer Classification	Target Organ/System
Cyclohexanone	000108-94-1	-	whole body
DDD	000072-54-8	B2	spleen, liver
DDE, p,p'-	000072-55-9	B2	liver
DDT	000050-29-3	B2	liver
Dibenz[a,h]anthracene	000053-70-3	B2	-
Dibromochloromethane	000124-48-1	C	liver
Dibutyl Phthalate	000084-74-2	D	-
Dichlorobenzene, 1,2-	000095-50-1	D	whole body
Dichlorobenzene, 1,4-	000106-46-7	C	liver
Dichlorobenzidine, 3,3'-	000091-94-1	B2	mammary
Dichloroethane, 1,1-	000075-34-3	C	kidney
Dichloroethane, 1,2-	000107-06-2	B2	kidney
Dichloroethylene, 1,1-	000075-35-4	C	liver, kidney, adrenal
Dichloroethylene, 1,2-cis-	000156-59-2	D	blood
Dichloroethylene, 1,2-trans-	000156-60-5	-	lung
Dichlorophenol, 2,4-	000120-83-2	-	-
Dichlorophenoxy Acetic Acid, 2,4-	000094-75-7	-	blood, liver, renal
Dichloropropane, 1,2-	000078-87-5	B2	nasal, liver
Dichloropropene, 1,3-	000542-75-6	B2	nasal, bronchioalveolar, bladder
Dieldrin	000060-57-1	B2	liver
Diethyl Phthalate	000084-66-2	D	-
Dimethylphenol, 2,4-	000105-67-9	-	-
Dinitro-o-cresol, 4,6-	000534-52-1	D	eye
Dinitrophenol, 2,4-	000051-28-5	-	eye
Dinitrotoluene, 2,4-	000121-14-2	-	-
Dinitrotoluene, 2,6-	000606-20-2	B2	whole body, liver
Diphenylhydrazine, 1,2-	000122-66-7	B2	liver
Endosulfan	000115-29-7	-	-
Endrin	000072-20-8	D	liver
Ethylbenzene	000100-41-4	B2	liver, kidney
Fluoranthene	000206-44-0	D	liver
Fluorene	000086-73-7	D	blood
Furan	000110-00-9	-	liver
Heptachlor	000076-44-8	B2	liver
Heptachlor Epoxide	001024-57-3	B2	liver
Hexachlorobenzene	000118-74-1	B2	liver
Hexachlorobutadiene	000087-68-3	C	kidney
Hexachlorocyclohexane, Alpha- (α-HCH)	000319-84-6	B2	liver
Hexachlorocyclohexane, Beta- (β-HCH)	000319-85-7	C	liver
Hexachlorocyclohexane, Gamma- (γ-HCH)	000058-89-9	B2-C	liver, kidney

Table E.4 Cancer Classification and Target Organ / System (URL 3) (cont'd)

Compound	CAS No.	Cancer Classification	Target Organ/System
Hexachlorocyclopentadiene	000077-47-4	E	nasal cavity, stomach
Hexachloroethane	000067-72-1	C	kidney, liver
Indeno[1,2,3-cd]pyrene	000193-39-5	B2	-
Isophorone	000078-59-1	C	preputial gland
MCPA	000094-74-6	-	kidney, liver
Maneb	012427-38-2	-	thyroid
Methoxychlor	000072-43-5	D	-
Methyl tert-Butyl Ether (MTBE)	001634-04-4	-	liver, kidney
Methylene Chloride	000075-09-2	B2	liver, lung
Mirex	002385-85-5	B2	liver
Naphthalene	000091-20-3	C	nasal
Nitrobenzene	000098-95-3	likely to be carcinogen	liver, kidney, thyroid
Nitroso-di-N-propylamine, N-	000621-64-7	B2	liver
Nitrosodimethylamine, N-	000062-75-9	B2	liver
Nitrosodiphenylamine, N-	000086-30-6	B2	eye, bladder
Pentachlorobenzene	000608-93-5	D	liver, kidney
Pentachlorophenol	000087-86-5	B2	liver, kidney
Phenol	000108-95-2	D	-
Polychlorinated Biphenyls (high risk)	001336-36-3	B2	liver
Polychlorinated Biphenyls (low risk)	001336-36-3	B2	liver
Pyrene	000129-00-0	D	kidney
Pyridine	000110-86-1	-	liver
Styrene	000100-42-5	-	-
Tetrachlorobenzene, 1,2,4,5-	000095-94-3	-	kidney
Tetrachlorodibezo-p-Dioxin, 2,3,7,8-	001746-01-6	B2	respiratory system
Tetrachloroethane, 1,1,1,2-	000630-20-6	C	liver
Tetrachloroethylene	000127-18-4	-	kidney, liver
Toluene	000108-88-3	D	kidney
Total Petroleum Hydrocarbons (Aliphatic) (EC16> - EC35)	000000-00-9	-	liver
Total Petroleum Hydrocarbons (Aliphatic) (EC5 - EC8)	000000-01-0	-	nervous system
Total Petroleum Hydrocarbons (Aliphatic) (EC8> - EC16)	000000-01-1	-	-
Total Petroleum Hydrocarbons (Aromatic) (EC16> - EC35)	000000-01-2	-	kidney
Total Petroleum Hydrocarbons (Aromatic) (EC5 - EC9)	000000-01-3	-	liver, kidney
Total Petroleum Hydrocarbons (Aromatic) (EC9> - EC16)	000000-01-4	-	nasal
Toxaphene	008001-35-2	B2	liver
Tributyltin Oxide	000056-35-9	D	-

Table E.4 Cancer Classification and Target Organ / System (URL 3) (cont'd)

Compound	CAS No.	Cancer Classification	Target Organ/System
Trichlorobenzene, 1,2,4-	000120-82-1	D	liver
Trichloroethane, 1,1,1-	000071-55-6	D	liver
Trichloroethane, 1,1,2-	000079-00-5	C	liver
Trichloroethylene	000079-01-6	-	-
Trichlorophenol, 2,4,5-	000095-95-4	-	liver, kidney
Trichlorophenol, 2,4,6-	000088-06-2	B2	blood
Vinyl Acetate	000108-05-4	-	nasal, whole body
Vinyl Chloride	000075-01-4	A	liver
Xylene, Mixture	001330-20-7	D	-
Xylene, m-	000108-38-3	-	central nervous system
Xylene, o-	000095-47-6	-	central nervous system
Xylene, p-	000106-42-3	-	-
INORGANICS			
Arsenic, Inorganic	007440-38-2	A	lung, skin
Barium	007440-39-3	D	fetus, liver
Beryllium and compounds	007440-41-7	B1	small intestine, lung
Cadmium (Diet)	007440-43-9	B1	lung
Chromium (III) (Insoluble Salts)	016065-83-1	D	-
Chromium VI (particulates)	018540-29-9	A	nasal, lung
Chromium, Total (1:6 ratio Cr VI : Cr III)	007440-47-3	-	-
Cobalt	007440-48-4	B1	lung
Copper	007440-50-8	-	-
Cyanide (CN-)	000057-12-5	D	-
Lead and Compounds	007439-92-1	-	-
Mercury (elemental)	007439-97-6	D	-
Molybdenum	007439-98-7	-	-
Nickel Soluble Salts	007440-02-0	-	-
Selenium	007782-49-2	D	-
Silver	007440-22-4	D	-
Tetraethyl Lead	000078-00-2	-	liver
Thallium (Soluble Salts)	007440-28-0	D	-
Thiocyanate	000463-56-9	-	thyroid
Tin	007440-31-5	-	liver
Titanium Tetrachloride	007550-45-0	-	-
Vanadium, Metallic	007440-62-2	-	-
Zinc (Metallic)	007440-66-6	D	-

APPENDIX-F

AERMOD MODEL RUN SHEETS

```
                    AERMOD PRIME - (DATED 09292)

CO STARTING
CO TITLEONE  AREA 0.01ha
CO MODELOPT  DFAULT  CONC
CO RUNORNOT  RUN
CO AVERTIME  PERIOD
CO POLLUTID  OTHER
CO FINISHED

SO STARTING
SO ELEVUNIT  METERS
SO LOCATION  0.01HA    AREA      495  495  0
SO SRCPARAM  0.01HA    1  0  10  10  0  0
SO CONCUNIT  1.0E-03  GRAMS/SEC  KILOGRAMS/M**3
SO SRCGROUP  ALL
SO FINISHED

RE STARTING
RE ELEVUNIT  METERS
RE GRIDCART RCPT STA
RE GRIDCART RCPT XYINC  495  3  5  495  3  5
RE GRIDCART RCPT ELEV  1  0  0  0
RE GRIDCART RCPT ELEV  2  0  0  0
RE GRIDCART RCPT ELEV  3  0  0  0
RE GRIDCART RCPT HILL  1  0  0  0
RE GRIDCART RCPT HILL  2  0  0  0
RE GRIDCART RCPT HILL  3  0  0  0
RE GRIDCART RCPT END
RE FINISHED

ME STARTING
ME SURFFILE  "C:\BREEZE\17351.SFC"
** SURFFILE  "C:\BREEZE\17351.SFC"
ME PROFFILE  "C:\BREEZE\17351.PFL"
** PROFFILE  "C:\BREEZE\17351.PFL"
ME SURFDATA  00017351  2003  ADANA
ME UAIRDATA  00017351  2003  ADANA
ME SITEDATA  17351  2003  ADANA
ME PROFBASE  20
ME FINISHED

OU STARTING
OU FILEFORM FIX
OU PLOTFILE  PERIOD  ALL  ALL`PERIOD.plt  10
OU FINISHED
```

```
********************************************************************
It is recommended that the user not edit any data below this line
********************************************************************

** AMPTYPE
** AMPDATUM  -1
** AMPZONE  -1
** AMPHEMISPHERE
** PROJECTION  UTM
** DATUM  WGE
** UNITS  METER
** ZONE  2
** HEMISPHERE  N
** ORIGINLON  0
** ORIGINLAT  0
** PARALLEL1  0
** PARALLEL2  0
** AZIMUTH  0
** SCALEFACT  0
** FALSEEAST  0
** FALSENORTH  0

** POSTFMT  UNFORM
** TEMPLATE REGULATORY,-1
** AERMODEXE  AERMOD_BREEZE_09292.EXE
** AERMAPEXE


  *** Message Summary For AERMOD Model Setup ***

  --------- Summary of Total Messages --------

 A Total of            0 Fatal Error Message(s)
 A Total of            0 Warning Message(s)
 A Total of            0 Informational Message(s)


    ******** FATAL ERROR MESSAGES ********
               ***  NONE  ***


    ********   WARNING MESSAGES   ********
               ***  NONE  ***

 ***********************************
 *** SETUP Finishes Successfully ***
 ***********************************
```

```
             ***     MODEL SETUP OPTIONS SUMMARY       ***
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 **Model Is Setup For Calculation of Average CONCentration Values.

   --  DEPOSITION LOGIC  --
 **NO GAS DEPOSITION Data Provided.
 **NO PARTICLE DEPOSITION Data Provided.
 **Model Uses NO DRY DEPLETION.  DRYDPLT  =  F
 **Model Uses NO WET DEPLETION.  WETDPLT  =  F

 **Model Uses RURAL Dispersion Only.

 **Model Uses Regulatory DEFAULT Options:
         1. Stack-tip Downwash.
         2. Model Accounts for ELEVated Terrain Effects.
         3. Use Calms Processing Routine.
         4. Use Missing Data Processing Routine.
         5. No Exponential Decay.

 **Model Assumes No FLAGPOLE Receptor Heights.

 **Model Calculates PERIOD Averages Only

 **This Run Includes:      1 Source(s);       1 Source Group(s); and
9 Receptor(s)

 **The Model Assumes A Pollutant Type of:  OTHER

 **Model Set To Continue RUNning After the Setup Testing.

 **Output Options Selected:
          Model Outputs Tables of PERIOD Averages by Receptor
          Model Outputs External File(s) of High Values for Plotting
         (PLOTFILE Keyword)

 **NOTE:  The Following Flags May Appear Following CONC Values:
c for Calm Hours
m for Missing Hours
b for Both Calm and Missing Hours

 **Misc. Inputs:  Base Elev. for Pot. Temp. Profile (m MSL) = 20.00
;  Decay Coef. =    0.000     ;  Rot. Angle =     0.0
Emission Units = GRAMS/SEC ; Emission Rate Unit Factor = 0.10000E-02
Output Units   = KILOGRAMS/M**3

 **Approximate Storage Requirements of Model =      3.5 MB of RAM.

 **Input Runstream File:          AERMOD.INP
 **Output Print File:             AERMOD.OUT


                      *** AREA SOURCE DATA ***

              NUMBER EMISSION RATE  COORD (SW CORNER)  BASE
RELEASE  X-DIM     Y-DIM    ORIENT.    INIT.   URBAN  EMISSION RATE
    SOURCE     PART. (USER UNITS       X        Y      ELEV.
HEIGHT  OF AREA   OF AREA   OF AREA     SZ     SOURCE  SCALAR VARY
```

```
      ID       CATS.   /METER**2)   (METERS) (METERS) (METERS)
(METERS) (METERS)  (METERS)   (DEG.)  (METERS)              BY
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   0.01HA        0   0.10000E+01     495.0     495.0     0.0
0.00     10.00     10.00      0.00     0.00     NO

              *** SOURCE IDs DEFINING SOURCE GROUPS ***

 GROUP ID                  SOURCE IDs    ALL       0.01HA  ,

              *** GRIDDED RECEPTOR NETWORK SUMMARY ***

       *** NETWORK ID: RCPT     ;  NETWORK TYPE: GRIDCART ***

                    *** X-COORDINATES OF GRID ***
 (METERS)         495.0,     500.0,     505.0,

                    *** Y-COORDINATES OF GRID ***
 (METERS)         495.0,     500.0,     505.0,

       *** NETWORK ID: RCPT     ;  NETWORK TYPE: GRIDCART ***

                   * ELEVATION HEIGHTS IN METERS *
    Y-COORD  |     X-COORD (METERS)
    (METERS) |        495.00       500.00       505.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      505.00 |          0.00         0.00         0.00
      500.00 |          0.00         0.00         0.00
      495.00 |          0.00         0.00         0.00


       *** NETWORK ID: RCPT     ;  NETWORK TYPE: GRIDCART ***

                  * HILL HEIGHT SCALES IN METERS *
    Y-COORD  |     X-COORD (METERS)
    (METERS) |        495.00       500.00       505.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      505.00 |          0.00         0.00         0.00
      500.00 |          0.00         0.00         0.00
      495.00 |          0.00         0.00         0.00

*** METEOROLOGICAL DAYS SELECTED FOR PROCESSING *** (1=YES; 0=NO)

1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1

NOTE:  METEOROLOGICAL DATA ACTUALLY PROCESSED WILL ALSO DEPEND ON
WHAT IS INCLUDED IN THE DATA FILE.


  *** UPPER BOUND OF FIRST THROUGH FIFTH WIND SPEED CATEGORIES ***
                           (METERS/SEC)

               1.54,   3.09,   5.14,   8.23,  10.80,
```

```
                   *** UP TO THE FIRST 24 HOURS OF METEOROLOGICAL DATA ***
  Surface file:   C:\BREEZE\ADANA.SFC                                       Met Version:  06341
  Profile file:   C:\BREEZE\ADANA.PFL
  Surface format: FREE
  Profile format: FREE
  Surface station no.:    17351     Upper air station no.:    17351
  Name: ADANA                       Name: ADANA
  Year:   2003                      Year:   2003
 First 24 hours of scalar data
 YR MO DY JDY HR     H0     U*     W*  DT/DZ ZICNV ZIMCH  M-O LEN    Z0  BOWEN ALBEDO  REF WS   WD     HT  REF TA     HT
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 03 01 01   1 01   -0.3  0.019 -9.000 -9.000 -999.    6.      2.3  0.05   1.50   1.00    0.50    1.   10.0  281.4    2.0
 03 01 01   1 02   -0.3  0.019 -9.000 -9.000 -999.    6.      2.3  0.05   1.50   1.00    0.50  358.   10.0  282.0    2.0
 03 01 01   1 03   -1.0  0.038 -9.000 -9.000 -999.   17.      4.6  0.05   1.50   1.00    1.00    4.   10.0  281.4    2.0
 03 01 01   1 04   -5.6  0.098 -9.000 -9.000 -999.   71.     15.4  0.05   1.50   1.00    2.10   23.   10.0  281.4    2.0
 03 01 01   1 05   -1.0  0.038 -9.000 -9.000 -999.   18.      4.6  0.05   1.50   1.00    1.00   23.   10.0  281.4    2.0
 03 01 01   1 06   -2.4  0.057 -9.000 -9.000 -999.   31.      7.0  0.05   1.50   1.00    1.50   22.   10.0  283.1    2.0
 03 01 01   1 07   -2.4  0.057 -9.000 -9.000 -999.   31.      7.0  0.05   1.50   1.00    1.50   25.   10.0  282.5    2.0
 03 01 01   1 08   -2.1  0.057 -9.000 -9.000 -999.   31.      7.6  0.05   1.50   0.54    1.50   23.   10.0  283.1    2.0
 03 01 01   1 09    2.6  0.087  0.063  0.005    3.   60.    -23.1  0.05   1.50   0.34    1.00   17.   10.0  283.1    2.0
 03 01 01   1 10   15.4  0.137  0.215  0.005   23.  116.    -15.0  0.05   1.50   0.26    1.50   21.   10.0  283.1    2.0
 03 01 01   1 11   23.9  0.142  0.331  0.005   55.  123.    -10.7  0.05   1.50   0.24    1.50   24.   10.0  283.1    2.0
 03 01 01   1 12   27.7  0.107  0.412  0.005   91.   81.     -4.0  0.05   1.50   0.23    1.00   16.   10.0  283.8    2.0
 03 01 01   1 13   26.4  0.107  0.451  0.005  125.   80.     -4.2  0.05   1.50   0.23    1.00   23.   10.0  284.2    2.0
 03 01 01   1 14   19.9  0.140  0.437  0.005  151.  120.    -12.4  0.05   1.50   0.25    1.50   19.   10.0  284.2    2.0
 03 01 01   1 15    8.7  0.096  0.341  0.005  163.   69.     -9.2  0.05   1.50   0.30    1.00   22.   10.0  284.2    2.0
 03 01 01   1 16   -0.7  0.038 -9.000 -9.000 -999.   18.      6.8  0.05   1.50   0.43    1.00   24.   10.0  283.8    2.0
 03 01 01   1 17   -1.0  0.038 -9.000 -9.000 -999.   17.      4.6  0.05   1.50   1.00    1.00   21.   10.0  283.1    2.0
 03 01 01   1 18   -2.4  0.057 -9.000 -9.000 -999.   31.      7.0  0.05   1.50   1.00    1.50   17.   10.0  283.1    2.0
 03 01 01   1 19   -1.0  0.038 -9.000 -9.000 -999.   17.      4.6  0.05   1.50   1.00    1.00   24.   10.0  283.1    2.0
 03 01 01   1 20   -1.0  0.038 -9.000 -9.000 -999.   17.      4.6  0.05   1.50   1.00    1.00   17.   10.0  282.5    2.0
 03 01 01   1 21   -2.4  0.057 -9.000 -9.000 -999.   31.      7.0  0.05   1.50   1.00    1.50   20.   10.0  282.5    2.0
 03 01 01   1 22   -5.6  0.099 -9.000 -9.000 -999.   72.     15.7  0.05   1.50   1.00    2.10   22.   10.0  282.5    2.0
 03 01 01   1 23   -2.4  0.057 -9.000 -9.000 -999.   31.      7.0  0.05   1.50   1.00    1.50   20.   10.0  282.5    2.0
 03 01 01   1 24   -2.4  0.057 -9.000 -9.000 -999.   31.      7.0  0.05   1.50   1.00    1.50   20.   10.0  282.0    2.0
 First hour of profile data           YR MO DY HR HEIGHT F  WDIR    WSPD AMB_TMP sigmaA  sigmaW  sigmaV
                                      03 01 01 01   10.0 1    1.    0.50   281.5   99.0  -99.00  -99.00
 F indicates top of profile (=1) or below (=0)
```

```
*** THE PERIOD ( 57696 HRS) AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP: ALL ***
INCLUDING SOURCE(S):      0.01HA  ,

                            *** NETWORK ID: RCPT     ;  NETWORK TYPE: GRIDCART ***
                      ** CONC OF OTHER    IN KILOGRAMS/M**3                           **

    Y-COORD  |        X-COORD (METERS)
    (METERS) |        495.00       500.00       505.00
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      505.00 |       0.01900      0.02590      0.01059
      500.00 |       0.02529      0.03622      0.01454
      495.00 |       0.01635      0.02240      0.00863


                          *** THE SUMMARY OF MAXIMUM PERIOD ( 57696 HRS) RESULTS ***

                      ** CONC OF OTHER    IN KILOGRAMS/M**3                           **
                                                                   NETWORK
GROUP ID        AVERAGE CONC               RECEPTOR  (XR, YR, ZELEV, ZHILL, ZFLAG)  OF TYPE  GRID-ID
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
ALL      1ST HIGHEST VALUE IS 0.03622 AT (     500.00,      500.00,     0.00,     0.00,    0.00)  GC  RCPT
         2ND HIGHEST VALUE IS 0.02590 AT (     500.00,      505.00,     0.00,     0.00,    0.00)  GC  RCPT
         3RD HIGHEST VALUE IS 0.02529 AT (     495.00,      500.00,     0.00,     0.00,    0.00)  GC  RCPT
         4TH HIGHEST VALUE IS 0.02240 AT (     500.00,      495.00,     0.00,     0.00,    0.00)  GC  RCPT
         5TH HIGHEST VALUE IS 0.01900 AT (     495.00,      505.00,     0.00,     0.00,    0.00)  GC  RCPT
         6TH HIGHEST VALUE IS 0.01635 AT (     495.00,      495.00,     0.00,     0.00,    0.00)  GC  RCPT
         7TH HIGHEST VALUE IS 0.01454 AT (     505.00,      500.00,     0.00,     0.00,    0.00)  GC  RCPT
         8TH HIGHEST VALUE IS 0.01059 AT (     505.00,      505.00,     0.00,     0.00,    0.00)  GC  RCPT
         9TH HIGHEST VALUE IS 0.00863 AT (     505.00,      495.00,     0.00,     0.00,    0.00)  GC  RCPT
        10TH HIGHEST VALUE IS 0.00000 AT (       0.00,        0.00,     0.00,     0.00,    0.00)

 *** RECEPTOR TYPES:  GC = GRIDCART
                      GP = GRIDPOLR
                      DC = DISCCART
                      DP = DISCPOLR
```

```
*** Message Summary : AERMOD Model Execution ***

 --------- Summary of Total Messages --------

A Total of            0 Fatal Error Message(s)
A Total of            0 Warning Message(s)
A Total of        12646 Informational Message(s)

A Total of        57696 Hours Were Processed

A Total of        11982 Calm Hours Identified

A Total of          664 Missing Hours Identified (  1.15 Percent)


   ******** FATAL ERROR MESSAGES ********
              ***  NONE  ***


   ********   WARNING MESSAGES   ********
              ***  NONE  ***

   ************************************
   *** AERMOD Finishes Successfully ***
   ************************************
```

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: İPEK, Hatice Meltem
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Marital Status: Married
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EDUCATION

Degree	Institution	Year of Graduation
MS	METU Environmental Engineering	2004
BS	METU Environmental Engineering	2002
High School	Ankara Atatürk High School (Anatolian High School)	1998

WORK EXPERIENCE

Year	Place	Enrollment
2006-2009	METU Department of Environmental Engineering (TUBITAK Project: Development of an Environmental Management System for Sites Contaminated by Point Sources)	Project Assistant
2004-2006	Çınar Engineering Consultancy and Project Services Ltd.	Project Engineer

2002-2004	METU Department of Environmental Engineering (European Union Life Project: Odorous Emissions and Immisions Management in Turkey)	Technical Staff
2001 July - 2001 August	Bank of States (İller Bankası)	Intern Engineering Student
2000 July - 2000 August	Bank of States (İller Bankası)	Intern Engineering Student

FOREIGN LANGUAGES

Advanced English, Intermediate German, Beginning Italian

PUBLICATIONS

Papers Published in International Journals

1. Atimtay, A.T., Bayram, A., Bilgili, S., Bolcu, E., Demircioglu, H., Dincer, F., Fischer, K., Güvener, M., Homans, W.J., Müezzinoglu, A., Şahin, M., Sanalan, T., Tok, E., "Odorous Emissions and Immissions Management Policy in Turkey: A National Initiative", VDI- Berichte 1850, p. 61, 17-19, 2004, Germany.

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3. Kentel, E., Aksoy, A., Büyüker, B., Dilek, F., Girgin, S., İpek, H.M., Polat, Ş., Yetiş, Ü., Ünlü, K. (2010). Challenges in Development and Implementation of Health-Risk-Based Soil Quality Guidelines: Turkey's Experience. Risk Analysis, no. doi: 10.1111/j.1539-6924.2010.01533.x

National and International Conference Proceeding Publications

1. Güvener, M., Tüzün, M., Atimtay, A.T., 2003. "Üniversite Gençlerinde Sigaranın Kandaki Karboksi Hemoglobin ve Fizisel Aktivite Düzeyi Üzerindeki Etkilerinin İncelenmesi", VI. Ulusal Çevre Sorunlarına Öğrenci Yaklaşımları Sempozyumu", 1-3 Mayıs, 2003, Mersin.

2. Güvener, H. M., Atimtay, A.T., 2005. "Immission Measurements and Odor Percentage Determination Around a Confined Animal Feeding Site in Ankara", 25-28 Jan. 2005, New Orleans, USA.

3. Atimtay, A., Bayram, A., Bilgili, S., Bolcu, E., Demircioğlu, H., Dinçer, F., Fischer, K., Güvener, M., Homans, W. J., Müezzinoğlu, A., Şahin, M., Sanalan, A. T., Tok, E., 2005. "Türkiye'de Koku Emisyon ve İmisyonlarının Ölçülmesi ve Taslak Koku Yönetmeliğinin Oluşturulması", VI. Ulusal Çevre Mühendisliği Kongresi (ÇMO 2005), 24-26 Kasım 2005, İstanbul.

4. Ünlü, K., Güvener, M., Girgin, S., Yetiş, Ü., Dilek, F.B., Aksoy, A., Büyüker, B., Polat, Ş., 2008. "Endüstriyel Kaynaklı Kirlenmiş Sahalar için Çevre Yönetim Sistemi", *11th Symposium on Control of Industrial Pollution, 11-13 June 2008, İTÜ, İstanbul.*

5. Girgin, S., Güvener, M., Polat, Ş., Büyüker, B., Yetiş, Ü., Dilek, F.B., Aksoy, A., Ünlü, K., 2008. "Endüstriyel Kaynaklı Kirlenmiş Sahaların Yönetimi İçin Bilgi Sistemi Geliştirilmesi", *11th Symposium on Control of Industrial Pollution, 11-13 June 2008, İTÜ, İstanbul.*

Other Publications

Güvener, H. M., 2004. Investigation of Odorous Emissions and Immisions in Ankara with Olfactometer, M.Sc. Thesis, Middle East Technical University, Department of Environmental Engineering, Ankara.